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Vertical distribution of Xiphinema americanum in minimal and medial developed loess soil in southwest Iowa

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Vertical distribution of *Xiphinema americanum* in minimal and medial developed loess soil in southwest Iowa

by

Donald Peter Schmitt

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Approved:

Signature was redacted for privacy.

In Charge of Major Work

Signature was redacted for privacy.

Head of Major Department

Signature was redacted for privacy.

Dean of Graduate College

Iowa State University
Of Science and Technology
Ames, Iowa

1971

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INTRODUCTION

Several reports are extant on soil nematode population fluctuations and a few exist on the vertical distribution of nematodes in the soil profile. Theoretically, nematode populations are affected by hosts, cultural practices, and edaphic factors. The interaction of these factors result in a complex environment and may be the reason for some apparent contradictions in the literature concerning nematode behavior in soil. Comparative studies of single nematode species in several soils exist, but they have not contributed unequivocal information regarding the underlying causes for nematode fluctuations or patterns.

Xiphinema americanum Cobb is widespread, and in addition to being an important parasite by itself, it is also a vector of viruses. In the northern latitudes, the nematode is probably more important on perennials than annuals and potentially is one of the nurseryman's greatest problems. Except for small swellings reported in some instances, the nematode does not cause malformed plants. Consequently, nurserymen are not aware of this organism and they may attribute damage caused by this nematode, such as stunted plants, to other factors.

A few ecological studies with *X. americanum* have been made, but have not included comparative studies involving soil properties. The purposes of this study were (i) to study the behavior of *X. americanum* on common lilac *Syringa vulgaris* L. variety President Lincoln in minimal and medial developed loess, and (ii) to attempt to elucidate soil factors that might be governing nematode populations.

LITERATURE REVIEW

Results of studies made on vertical distribution of soil nematodes reveal wide variations in nematode distribution in the soil profile. Most investigators have concentrated on the nematode and have given minimal regard to its environment. Extensive research on the comparative ecology of nematodes is lacking.

Nematode Distribution in Soil

Soil nematodes, like other soil microorganisms, are found wherever organic matter exists. Most soil organic matter is derived from residues of higher plants, and is usually concentrated in the zone of greatest rhizosphere activity. The amount and distribution of organic matter varies with vegetation because the divergent flora have different rates of decomposition. One would expect to find the greater percentage of nematodes, especially plant-parasitic nematodes, in the rhizosphere.

Vertical distribution in the soil profile

In general, it is a world wide trend for the greatest numbers of nematodes to occur in the uppermost 15 cm of soil, yet relatively high numbers often occur from 15-30 cm (1, 12, 28, 35, 49). This vertical nematode distribution is affected by season (1, 35). For example, *Belonolaimus longicaudatus* Rau numbers were relatively high from 0-30 cm in the fall, but were most abundant in the 7.5-15.0 cm level in the winter (1). Even within a local area for a given date, the vertical distribution of nematode varies among fields and among crops or in fallow soil (1).

Greatest concentrations of some nematodes have been found deeper than 30 cm and below the area of greatest root density (6, 12, 21).

Although patterns of nematode distribution have been discovered, little has been done to explain these phenomena. An endeavor of this type was made with *Hemicycliophora similis* Thorne distribution in cranberry soils (50). In a young bog, 91.6% of the nematodes were in the top 6 inches and were concentrated in the lower 4 inches, whereas in an old bog, the greatest concentration was at 0-2 inches. The upper 4 inches of the old bog contained 78% of the population and 90% was in the upper 6 inches. This ratio existed throughout the year unless excessive drying occurred. A greater number of nematodes occurred at the lower levels before than after irrigation and this was interpreted as migration. Increase of organic matter content over 3% in the old bog was attributed to providing a satisfactory environment for the nematode, thus accounting for the concentration of *H. similis* in the top 2 inches of soil.

The change in number of nematodes with depth may be coincident with other changes. The proportion of adults to juveniles may change with depth. For example, percentage of adults of *Xiphinema diversicaudatum* (Micoletzky) Thorne in East Britain (21) and *Longidorus elongatus* (deMan) Thorne and Swanger in Germany (49) increased with depth, whereas the proportion of *X. diversicaudatum* adults and juveniles in southeastern England changed little with depth (12). Nematode survival may be greater in the upper than in lower soil levels (19).

Nematode distribution in relation to root distribution

The distribution of plant-parasitic nematodes is often assumed to be positively correlated with root density. Xiphinema americanum in Iowa (29) and Wisconsin (19), X. diversicaudatum in Israel (6), X. vuittenezi Luc, Lima, Weischer, and Flegg in England (12), and Hemicycliophora similis in Massachusetts (50) were positively correlated with root density. Numbers of X. diversicaudatum (12, 21) were poorly correlated with root density which indicates that other factors may be important in some instances.

Population Fluctuations

Population fluctuation patterns of nematodes differ with species of nematodes and within the same species in various geographical areas. Numbers of many nematodes are low in frozen or cold soil with population peaks occurring during the warm season (7, 19, 27, 29, 35, 49, 50). Conversely, numbers of nematodes may be high in winter and low in spring and summer in areas where soils never freeze (14, 28, 41). As examples, populations of H. similis in Massachusetts contained their greatest numbers in July with the minimum numbers occurring in February (50), whereas population peaks of H. arenaria Raski in California occurred in January and minimum numbers were found in August (41).

Proportions of adults and juveniles change throughout the year. Adult to juvenile ratios of Longidorus profundorum Hopper, L. macrosoma Hopper, X. vuittenezi were greatest during the egg laying period (13). Juveniles always composed the greater part of the population (13).

Population fluctuations of X. americanum follow similar trends in different geographical areas. Two population peaks of X. americanum occurred during the growing season in Iowa (29), Wisconsin (19), South Dakota (27), Kentucky (15, 16), and Massachusetts (7). The early peak usually occurred during late spring to early summer and the late peak during late summer to fall. Gravid female occurrence, by and large, was coincident with the population peaks (16, 19, 29), except they did not occur with the latest peak in South Dakota (27).

Eggs (19, 27, 29) and a few juveniles (19) of X. americanum were the only stages to survive the winter in these northern states. Juveniles were the first to increase as soil temperature began to rise (19). This was followed by the appearance of adults (19, 27), and gravid females (19, 27, 29) as soil temperatures continued to increase. Juvenile to adult ratios of about 8:1 occurred throughout the year in South Dakota (27), and juveniles were generally predominant in Iowa (29) and Wisconsin (19) during the growing season.

Soil Type and Nematode Abundance

The spacial relationship of a nematode to its environment appears to be important to the successful establishment of a given species. Greatest numbers or most injurious nematodes are often found in coarse or medium textured soils (6, 9, 21, 24, 46). Other nematodes are dominant in heavy soils (6, 48). Some nematode species are abundant in coarse (4, 24, 43, 44) and fine soils (24). In one study, the proportion of the components of silt and clay were found to be important (9).

The ecological amplitude of a nematode species may be limited by nematode size. Juveniles of Heterodera Schmidt, Trichodorus Cobb, and early juvenile stages of Longidorus (Micoletzky) Filipjev averaged 20 μ in diameter and could not penetrate the fine fraction of clay or silt, or the finer fractions of fine sand (24). Males were 30-60 μ in diameter and could not penetrate pores formed by particles smaller than coarse sand (24). _Xiphinema diversicaudatum_ adults were about 4000 X 60 μ and inhabited clefts between relatively large compacted aggregates and were not inside the soil aggregates (24). This species was confined to the major cracks and fissures between peds in untilled soil with much clay (24).

The ability of a nematode to establish and persist in an environment may be altered by vegetation. The host plant was more important for the distribution and abundance of _Heterodera_ than was soil type but the reverse was true for _Longidorus_ and _Trichodorus_ (24). Several _Pratylenchus_ Filipjev species and _Tylenchorhynchus_ Cobb species were more associated with the crop than soil type (48). For example, populations of _P. zeae_ Graham and _P. brachyurus_ (Godfrey) Filipjev and Stekhoven were greater in sandy loam or loam than in sand and clay loam when strawberry was the host. When tobacco was the host, the populations were much greater in sandy loam than in any other soil type (10).

MATERIALS AND METHODS

Sites were selected and experiments were designed to compare population development and fluctuations of *X. americanum* in minimally and medially developed loess soil. These soils were selected because they were derived from homogenous parent material which eliminates many variables that exist in soils derived from material such as glacial till.

Vertical Distribution of *Xiphinema americanum* in the Field

Site description

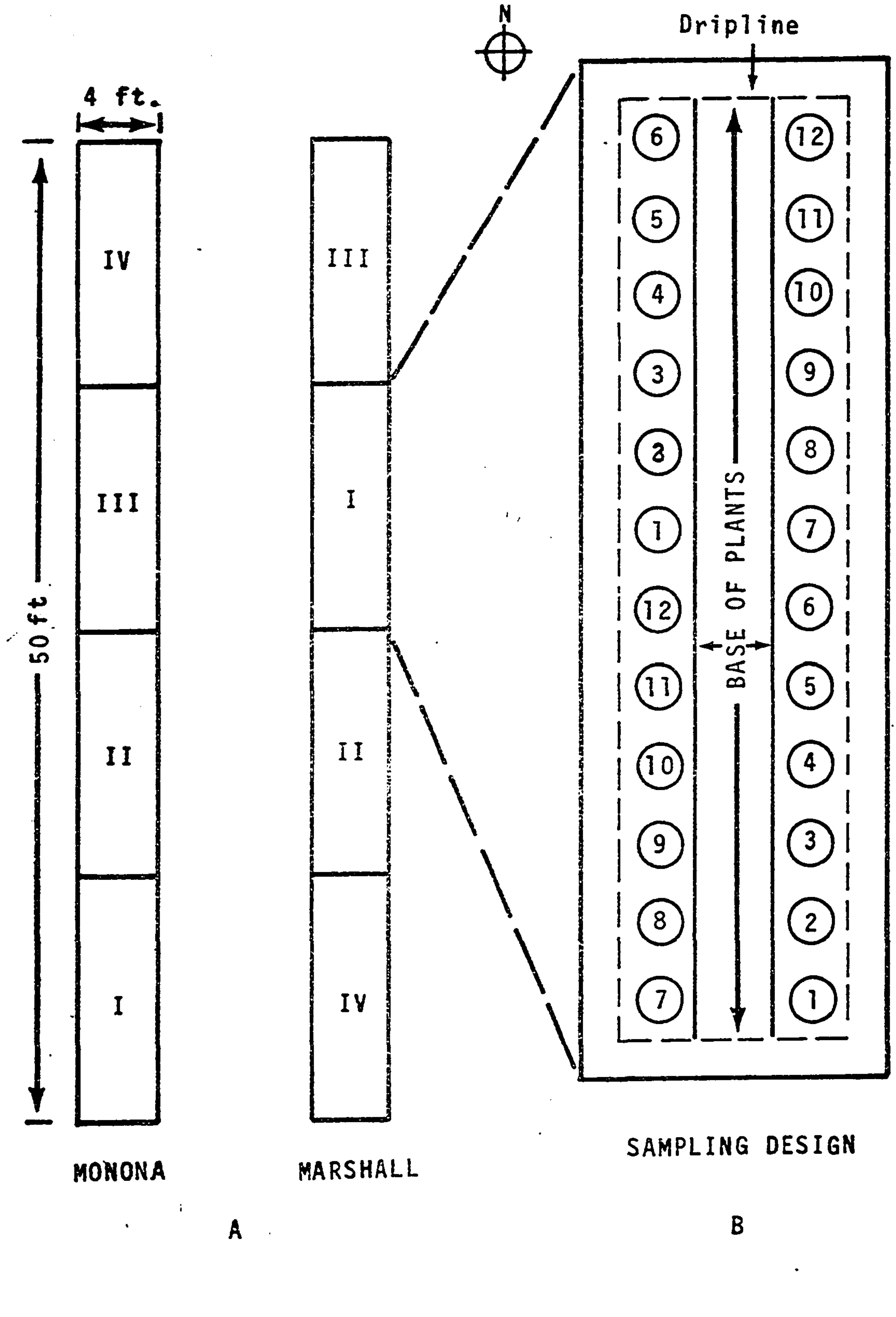
President Lincoln lilac stool blocks located in Monona silt loam soil on a bluff at Interstate Nurseries Farm #1, Hamburg, Iowa and in Marshall silty clay loam 1.5 miles east of the Mount Arbor Nurseries greenhouses in Shenandoah, Iowa were selected for this study. The Monona soil is minimally developed loess and belongs to the Monona-Ida-Hamburg soil association. This association is located predominantly in southwest to west central Iowa (30). Monona soils are well-drained and occur on the gently sloping narrow ridges and strongly sloping side slopes. The surface layer is a dark brown silt loam 8-14 inches thick. The subsoil is dark brown to brown silt loam. The medially developed Marshall soil belongs to the Marshall soil association which occurs in southwest and west central Iowa (30) and is immediately east of the Monona-Ida-Hamburg soil association. Marshall soils occur on nearly level to gently sloping upland divides and on gently sloping to steep side slopes. They are well-drained with dark brown silt clay loam surface layers 9-14 inches thick. The moderately permeable subsoil is a dark brown silty clay loam. The original vegetation of both soils was prairie. Both soils are extensively cultivated.

Experimental design of field plots

The experimental design for both plots is shown in Fig. 1, A-B. Each plot was divided into four replications. The soil at 0-3, 3-6, 6-9, 9-12, 12-15, 15-18, and 18-24 inch intervals in the soil profile were collected from each replicate with a 3 inch diameter soil bucket auger. Two samples were collected just inside the dripline from opposite sides of the plant for each replicate and composited at monthly intervals from August 1969 through September 1970, excluding January and February 1970. The holes resulting from the samplings were filled with soil after sampling and wooden garden stakes were placed in the center to identify the location. Each successive sample was taken 12 to 18 inches from the previous sample (Fig. 1, B). The composited soil samples were placed into polyethylene bags and taken to the laboratory for processing.

Nematodes were extracted from the soil 1 or 2 days after sampling by a modification of the Christie and Perry method (5). Basically, 250 cc of well mixed soil were wet sieved twice through a 35 mesh sieve with settling times of 10 and 30 sec, respectively, and once through the 100 and 200 mesh sieves with 30 sec settling time. The nematodes collected on the 200 mesh sieve were backwashed into a 4000 ml beaker. Water was added and roiled, allowing 15 sec settling time, and then poured onto a 325 mesh sieve. The nematodes collected on the 325 mesh sieve were placed in the Baermann funnel for 38 hr. The funnels were tapped and 10% of the extracted nematodes were randomly counted and identified to genus

Fig. 1. Schematic representation of the experimental plot design in the Monona silt loam and Marshall silty clay loam at Hamburg and Shenandoah, Iowa, respectively, 1969-1970. A. The division of 50 foot long plots into four replications. B. The order of sampling within each replication



4 ft.
50 ft
IV
III
II
I
MONONA
III
I
II
IV
MARSHALL
A
N
Dripline
6
5
4
3
2
1
12
11
10
9
8
7
12
11
10
9
8
7
6
5
4
3
2
1
BASE OF PLANTS
SAMPLING DESIGN
B

or species. Representative nematodes from each plant-parasitic taxon were relaxed by gentle heat and preserved in 5% formaldehyde. Some specimens were transferred to anhydrous glycerin, employing the method of Seinhorst (37), and mounted on metal slides.

The roots from every sample were caught on the 35 mesh sieve during the nematode extraction procedure. These roots were washed until all soil was removed and then were oven dried at 105 C and weighed.

Soil texture and field capacity (39); cation exchange capacity (34); percentage organic matter and percentage total nitrogen (34); parts per million ammonium, parts per million phosphorus, parts per million nitrate nitrogen and parts per million potassium (34); pH (34) and; electrical conductivity as a measure of soluble salts (3) were determined for each soil level in each replicate by the Iowa State University Agronomy department.

Soil moisture at each sampling period was determined and calculated as percentage of field capacity (39). Soil temperatures were taken in the Marshall soil at 3.0, 7.5, 12.0, and 17.0 inches from June 15 through August 31, 1970 and in the Monona soil at 3.0 and 12.0 inches from June 24 through July 8, 1970. Since these temperatures corresponded well with the soil temperatures for the same period as reported in "Climatological Data" (40), their soil temperatures will be used because they are complete for the entire sampling period.

Survival and migration of *Xiphinema americanum* in Laboratory Experiments

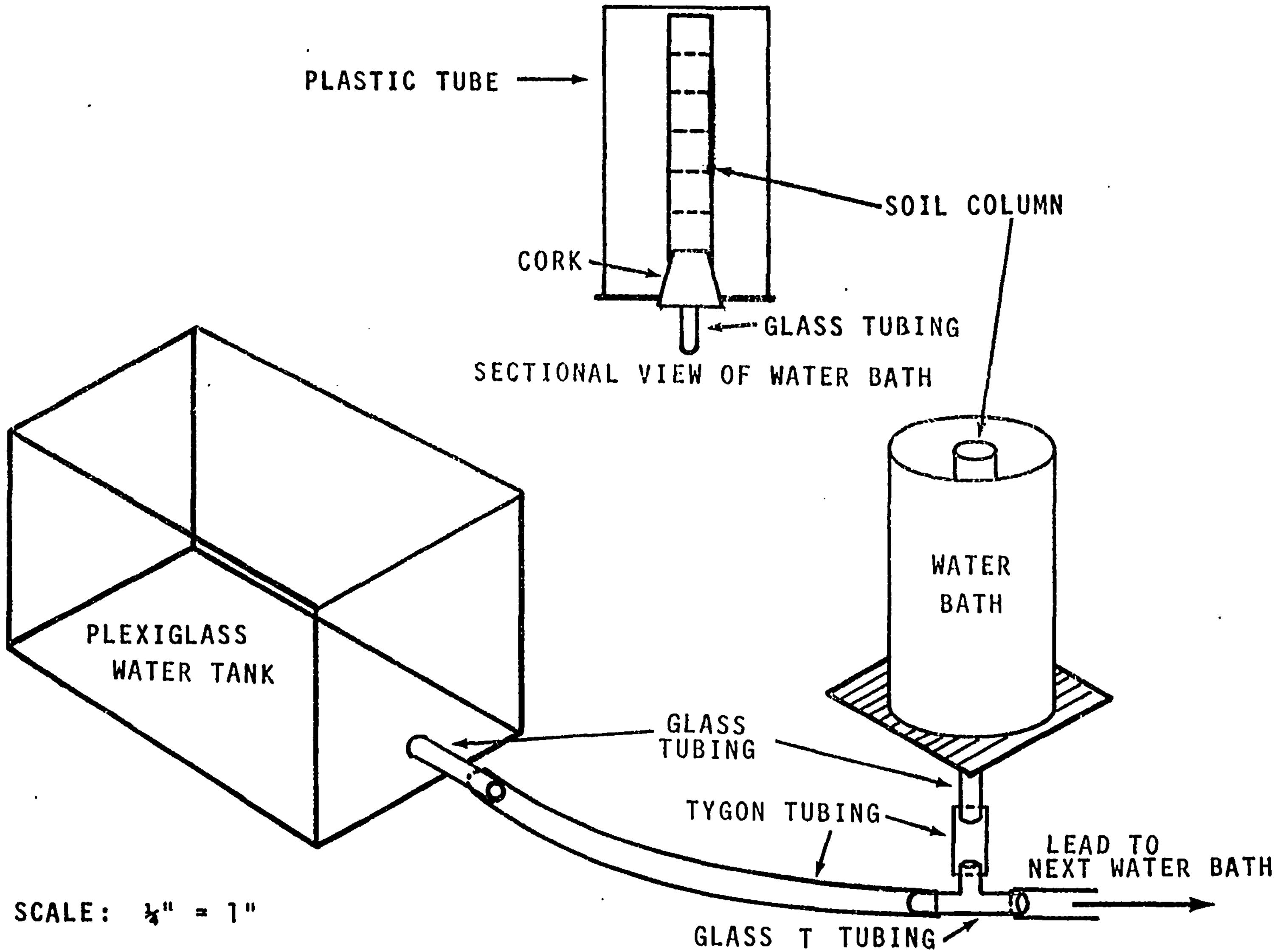
This experiment was designed to test the influence of the Monona and Marshall A and B horizons on the survival and migration of *X. americanum*.

The apparatus constructed for this study prevented sudden water and temperature changes in the nematode's environment (Fig. 2). A 6 X 6 X 12 inch water tank, which served as a water reservoir, was constructed of 0.125 inch thick plexiglass using epoxy glue as a weld. A soil column was constructed by taping together six 1 inch, or three 2 inch, glass cylinders with a 0.875 inch inside diameter. The water bath which served as a temperature buffer for the soil column was constructed of a 7 inch plastic cylinder with a 4 inch diameter. A 4 inch square 0.125 inch thick plexiglass with a 1 inch hole in the center was welded to the cylinder with epoxy glue. A number 10 cork with a 0.313 inch outside diameter glass tube in the center was inserted into the hole in the plexiglass plate. The soil column was fastened onto the cork in the plexiglass plate, stoppered with a cork, and immersed in warm wax to waterproof the soil column on the outside. The cork in the plexiglass plate was sealed with wax.

A small blotter was placed at the bottom of the soil column. Soil was added to half-fill the soil column. Xiphinema americanum was then added with a pipette and the remainder of the column was filled with soil.

The water baths were filled with water which served as a temperature buffer. The soil column was irrigated from the bottom by adjusting the water height in the water tank so that a certain level would be maintained in the soil column (Fig. 2). The soil moisture in the glass cylinders at the 0-2, 2-4, and 4-6 inch intervals was 152%, 189%, and 237% of field capacity for the Monona A horizon, 138%, 178%, and 224% of field capacity for the Monona B horizon, 103%, 144%, and 235% of field capacity for the Marshall A horizon, and 102%, 119%, and 181% of field capacity for the

Fig. 2. Apparatus used to study influence of the A and B soil horizons of Monona silt loam and Marshall silty clay loam on *Xiphinema americanum*


PLASTIC TUBE
SOIL COLUMN
CORK
GLASS TUBING
SECTIONAL VIEW OF WATER BATH
WATER BATH
PLEXIGLASS WATER TANK
GLASS TUBING
TYGON TUBING
LEAD TO NEXT WATER BATH
GLASS T TUBING
SCALE: ¼" = 1"

Marshall B horizon, respectively.

The experiment was conducted in a growth chamber. Experimental details of these experiments are presented in Table 1. Plants were not used in Experiment 1. Lilac seedlings were used in Experiment 2. Experiment 3 was subdivided so that lilac seedlings were used in half of the replicates. Each treatment consisted of two replications of one apparatus each for Experiments 1 and 3, and three replicates for Experiment 2.

Xiphinema americanum used for this experiment was collected from soil at the President Lincoln lilac stool blocks located in the Monona and Marshall soils. Infested soil was brought to the laboratory in large polyethylene bags and stored at room temperature until used. The nematodes were extracted by a centrifuge-flotation method (22). Basically, several 250 cc of soil were washed twice through a 35 and once through a 150 mesh sieve. The residue from the 150 mesh sieve was backwashed into a 4000 ml beaker. After the nematodes settled to the bottom of the beaker, the supernatant liquid was decanted. The remaining residue and liquid were transferred to 50 ml centrifuge tubes, and spun at 2000 RPM for 5 min. The supernatant liquid was decanted and sugar solution (sugar added to 700 ml of water to make a 1000 ml volume) was added, the residue and sugar were mixed and spun at 2000 RPM for 1 min. The supernatant containing the nematodes was washed onto a 400 mesh sieve and rinsed with fresh water. The nematodes were then washed into a beaker.

Experiments 1, 2, and 3 were terminated after 15, 28, and 34 days, respectively. The nematodes were extracted by a centrifuge-flotation technique as described. Soil in each glass cylinder section was processed individually. All nematodes in each section were counted.

Table 1. Experimental plan to test the influence of the Monona and Marshall A and B horizons on the migration and survival of *Xiphinema americanum*[a]

Experiment	Temperature[b] °C	Replications	Host[c]	*Xiphinema americanum* added/apparatus	Experiment duration (days)
1	27	2	Absent	600	15
	13-24	2	Absent	600	15
2	24	3	Present	320	28
	18-32	3	Present	320	28
3	18-27	2	Present	530	34
	18-27	2	Absent	530	34

[a] The photoperiod was 14 hours per day for every experiment.

[b] The low temperature occurred in the dark and the high temperature occurred when the lights were on.

[c] One lilac seedling/apparatus, if used.

RESULTS

Xiphinema americanum was the dominant plant-parasitic nematode in the lilac field test, but seldom constituted more than 50% of the total nematode population. The remaining nematode fauna consisted of several saprobic and plant-parasitic species. The small numbers of these species, however, did not contribute adequate ecological information for a comparative study. Therefore, only *X. americanum* data are included in this thesis.

Soil Analysis

The soil analyses of the Monona silt loam and the Marshall silty clay loam profiles are presented in table 2. The Marshall soil has a more developed profile than the Monona soil as evidenced by the greater clay illuviation, conspicuously darker upper 12 inches, and by the reddish underlying horizon in the Marshall soil compared with the virtual absence of these features in the Monona soil. The increasing cation exchange capacity with depth is an indication that profile development is beginning in the Monona soil, but it is not as conspicuous as in the Marshall soil.

Seasonal Population Fluctuations of *Xiphinema americanum*

Nematode numbers of *X. americanum* usually increased or decreased simultaneously at all levels at a given sampling (Fig. 3). Maximum numbers of *X. americanum* in both years in the Marshall soil and in 1969 in the Monona soil occurred in August. This was followed by a decline for the remainder of the year (Fig. 3). After a nematode increase in March and a

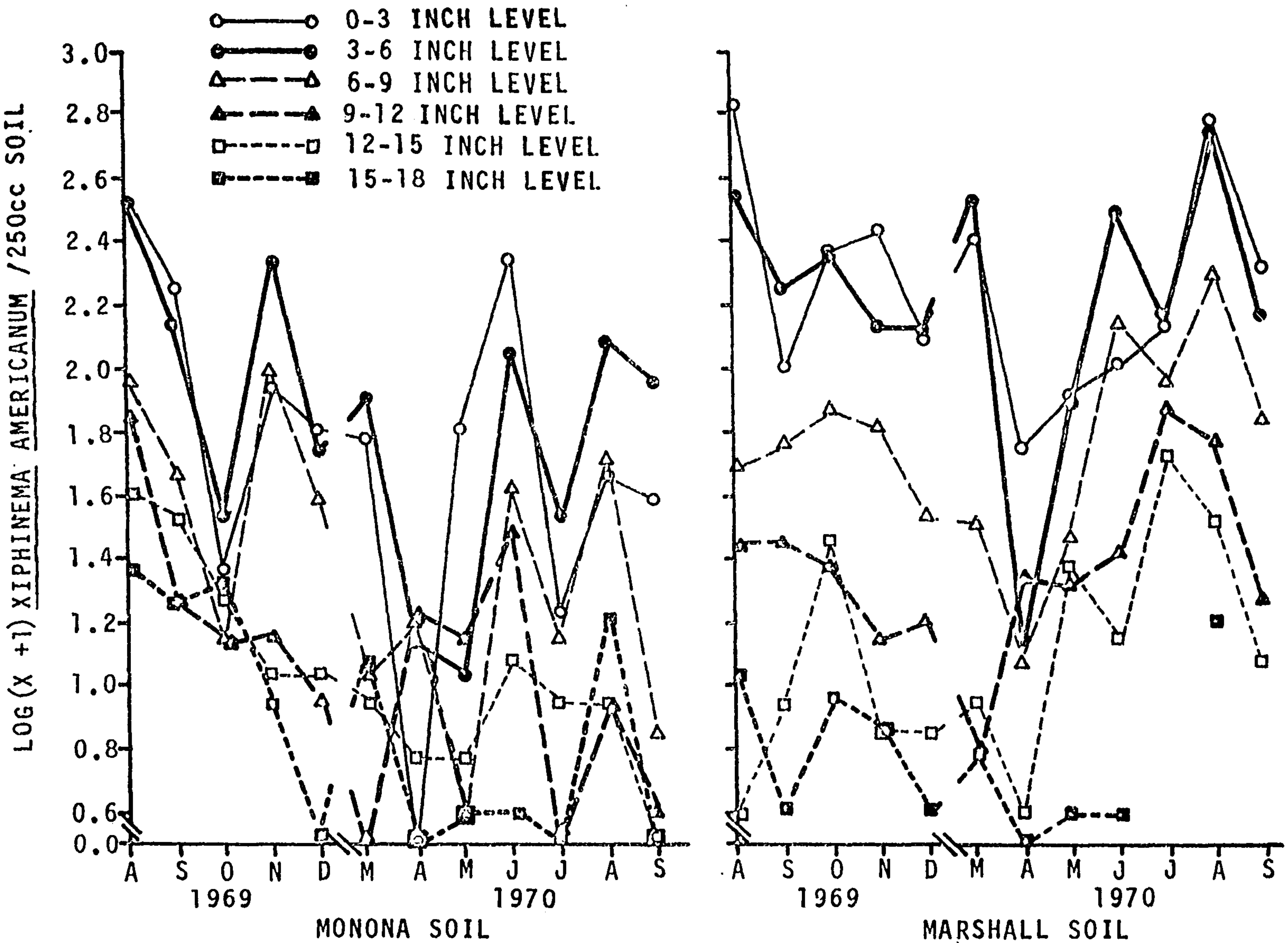
Table 2. Average soil analyses of the Monona silt loam and the Marshall silty clay loam soils at Hamburg and Shenandoah, Iowa, respectively, from August 1969 through October 1969

Depth	Sand	Silt	Clay	CEC[a]	Field Capacity	Organic Matter	N	NH_4^+	NO_3^-	P	K	pH	Electrical Conductivity[b]
Inches	%	%	%			%	%	ppm	ppm	ppm	ppm		mmho/cm
						Monona							
0-3	18.0	54.5	27.5	7.5	22.8	2.8	0.14	88	21	193	280	5.9	1.49
3-6	18.7	53.8	27.5	8.1	23.0	2.8	0.14	95	21	134	188	5.8	1.41
6-9	18.7	53.8	27.5	9.1	24.1	3.3	0.17	130	17	118	184	5.6	1.69
9-12	18.7	53.8	27.5	10.0	26.2	3.4	0.17	102	26	134	189	5.5	1.19
12-15	18.7	53.8	27.5	10.4	25.0	3.1	0.16	48	30	91	207	5.6	1.37
15-18	18.7	53.8	27.5	9.5	24.1	2.6	0.13	96	34	100	180	5.5	1.47
18-24	18.7	53.8	27.5	10.3	26.0	2.3	0.12	73	24	100	195	5.5	0.99
						Marshall							
0-3	15.7	53.8	30.5	11.2	27.2	3.1	0.16	112	36	556	345	5.4	0.63
3-6	15.7	53.8	30.5	11.9	24.5	3.3	0.14	108	33	426	272	5.0	0.50
6-9	15.7	51.9	32.4	13.3	26.6	2.8	0.14	121	34	358	231	4.8	0.69
9-12	15.7	48.7	35.6	14.7	27.6	3.1	0.16	108	46	187	185	4.6	0.45
12-15	15.7	50.6	33.7	17.0	30.3	3.0	0.15	140	51	179	201	4.6	0.47
15-18	15.7	50.0	34.3	17.8	30.2	2.8	0.14	71	29	109	206	4.8	0.45
18-24	15.7	48.0	36.3	19.0	28.9	2.4	0.12	74	21	164	200	4.8	0.30

[a] Cation exchange capacity; expressed as meq/100 g.

[b] Measure of soluble salts expressed as mmho/cm.

Fig. 3. Population fluctuations of *Xiphinema americanum* around President Lincoln lilac roots in Monona silt loam and Marshall silty clay loam at Hamburg and Shenandoah, Iowa, respectively, from August 1969 through September 1970


0-3 INCH LEVEL
3-6 INCH LEVEL
6-9 INCH LEVEL
9-12 INCH LEVEL
12-15 INCH LEVEL
15-18 INCH LEVEL
LOG (X +1) XIPHINEMA AMERICANUM /250cc SOIL
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.0
A S O N D M A M J J A S
1969
1970
MONONA SOIL
A S O N D M A M J J A S
1969
1970
MARSHALL SOIL

decrease in April 1970, a secondary peak occurred in June. Although population fluctuations at all levels generally followed a similar pattern, minor differences existed (Fig. 3). For example, populations increased at the 0-3 inch soil level, but decreased at the 3-6 inch soil level in November in the Marshall soil.

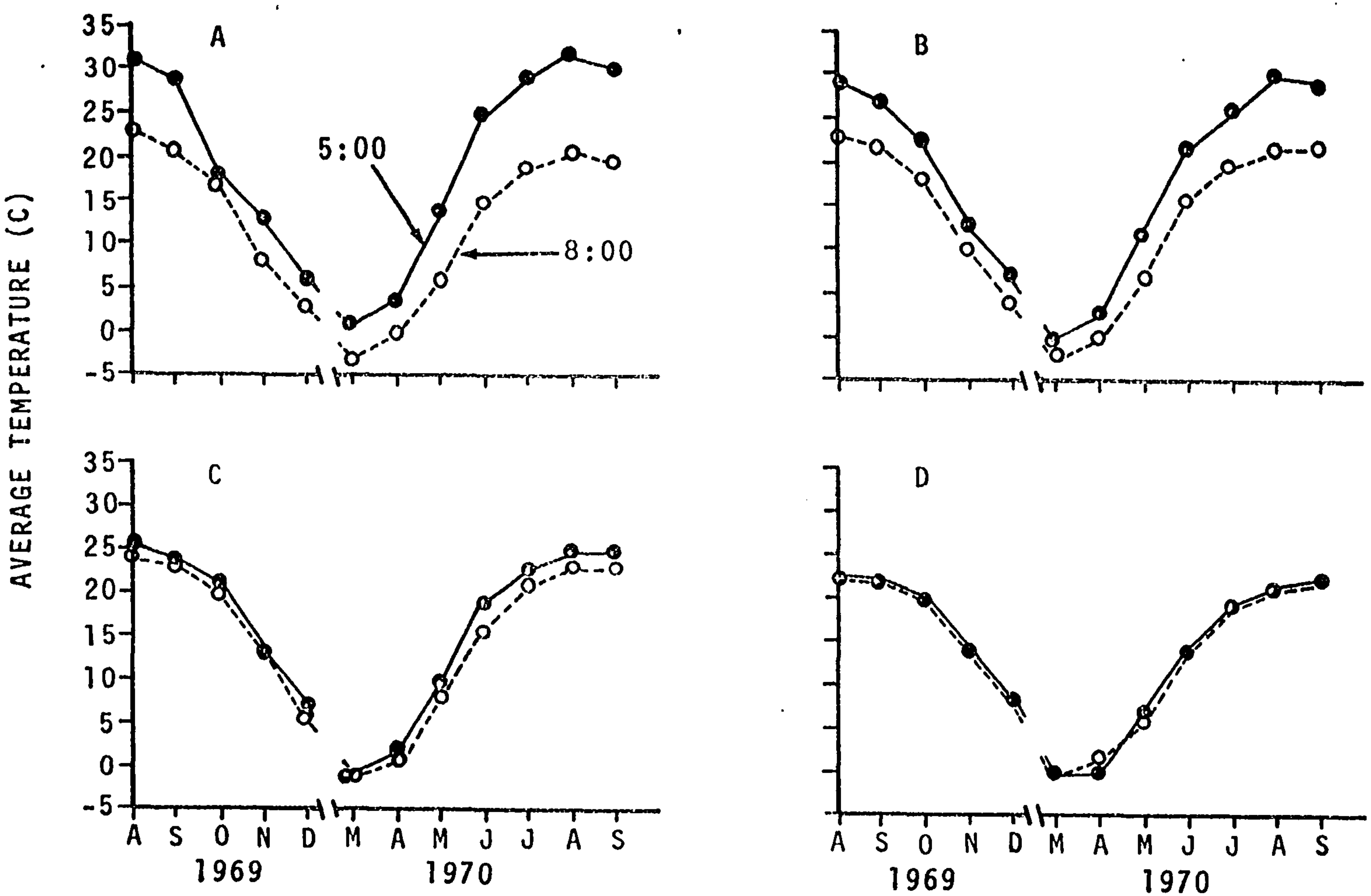
Numbers of X. americanum from all levels of the Monona soil were markedly smaller than from the Marshall soil during 1970 when the Monona soil received little precipitation. The Monona soil contained fewer nematodes in 1969, however, when both soils were adequately moist indicating that some factor or factors might inhibit reproduction and development of X. americanum.

Numbers of X. americanum did not closely coincide with soil temperature, but greater numbers were attained when the soil temperatures were high. Smaller numbers were generally found when the average monthly temperatures were low (Fig. 3-4, Table 3 appendix).

Fluctuation patterns of juveniles and adults were similar in each of the top four levels (Fig. 5, A-D). These nematode fluctuation patterns generally coincided with percentage of field capacity fluctuation patterns during the growing season. As the average monthly temperature decreased, however, the numbers of X. americanum decreased while the field capacity remained high (Fig. 3-5). Levels below 12 inches contained few nematodes and a difference of a few nematodes changed the fluctuation pattern (Fig. 5, E-G). Consequently, fluctuation patterns at the lower depths should not be considered a true representation of the actual pattern.

Adults and juveniles were positively correlated with each other over all depths and dates (r = 0.82). The adult to juvenile ratio increased

Fig. 4. Marshall silty clay loam soil temperature at Shenandoah, Iowa, reported in "Climatological Data" at 8:00 A.M. and 5:00 P.M. from August 1969 through September 1970. A. 2.25 inches; B. 4.00 inches; C. 8.00 inches; D. 20.00 inches



AVERAGE TEMPERATURE (C)
35
30
25
20
15
10
5
0
-5
A
B
C
D
5:00
8:00
A S O N D M A M J J A S
1969
1970

Fig. 5. Population fluctuation of *Xiphinema americanum* around President Lincoln lilac roots in Monona silt loam and Marshall silty clay loam soil at Hamburg and Shenandoah, Iowa, respectively, from August 1969 through September 1970. A. 0-3 inches; B. 3-6 inches; C. 6-9 inches; D. 9-12 inches; E. 12-15 inches; F. 15-18 inches; G. 18-24 inches

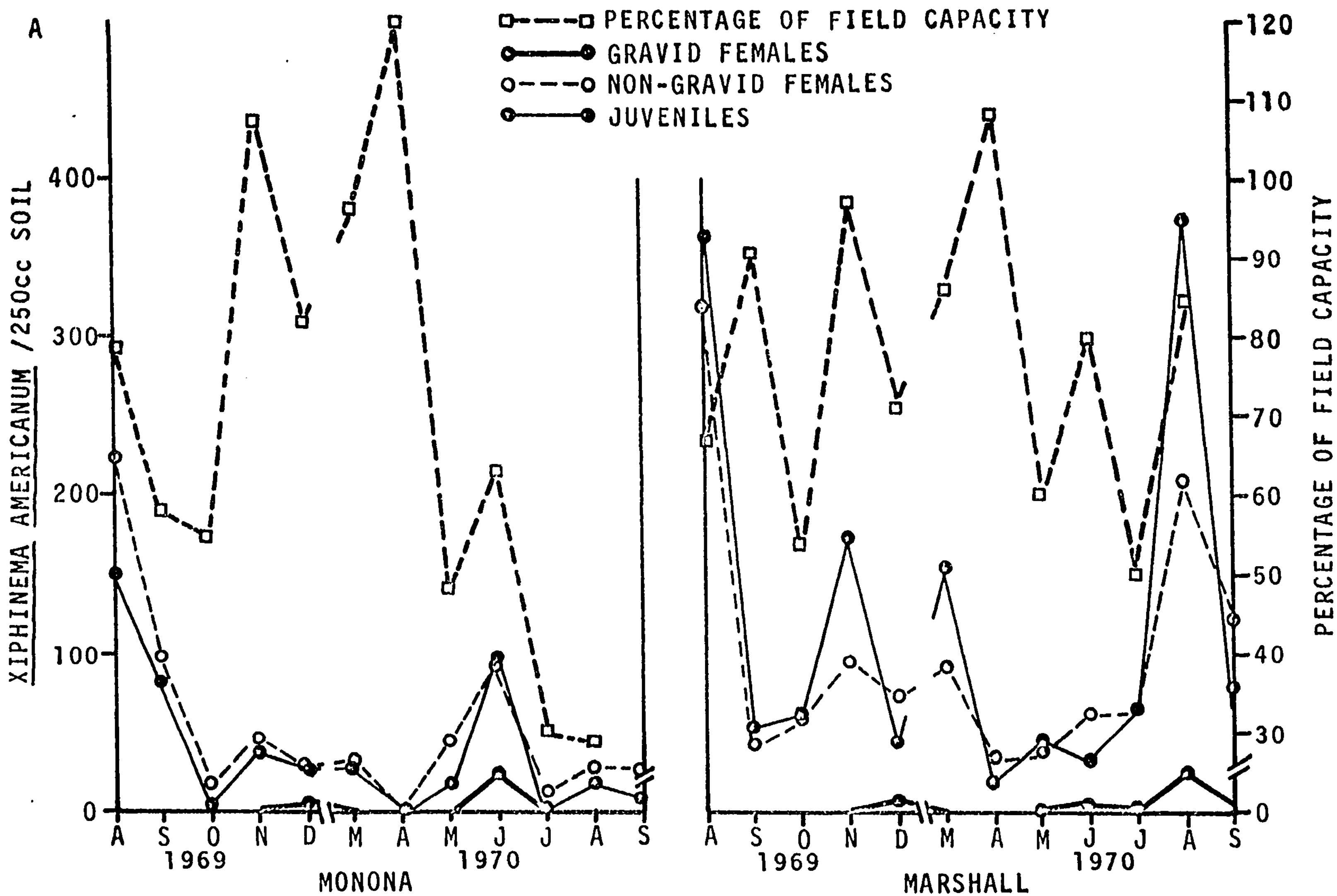
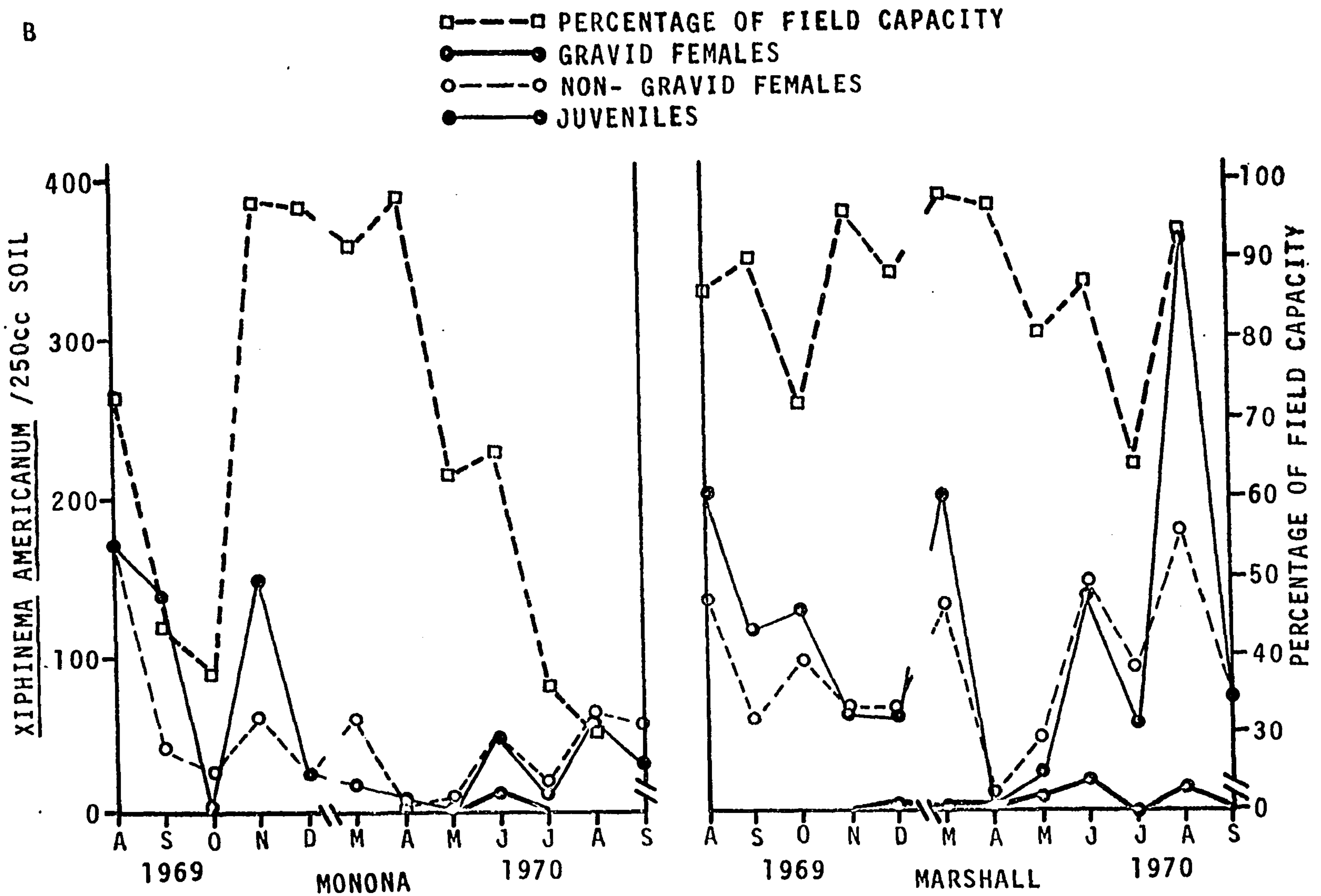

A
PERCENTAGE OF FIELD CAPACITY
GRAVID FEMALES
NON-GRAVID FEMALES
JUVENILES
XIPHINEMA AMERICANUM /250cc SOIL
PERCENTAGE OF FIELD CAPACITY
0
100
200
300
400
0
30
40
50
60
70
80
90
100
110
120
A S O N D M A M J J A S
1969
1970
MONONA
A S O N D M A M J J A S
1969
1970
MARSHALL

Fig. 5. (Continued)

B



PERCENTAGE OF FIELD CAPACITY
GRAVID FEMALES
NON- GRAVID FEMALES
JUVENILES
XIPHINEMA AMERICANUM /250cc SOIL
400
300
200
100
0
PERCENTAGE OF FIELD CAPACITY
100
90
80
70
60
50
40
30
0
A S O N D M A M J J A S
1969
MONONA
1970
A S O N D M A M J J A S
1969
MARSHALL
1970

Fig. 5. (Continued)

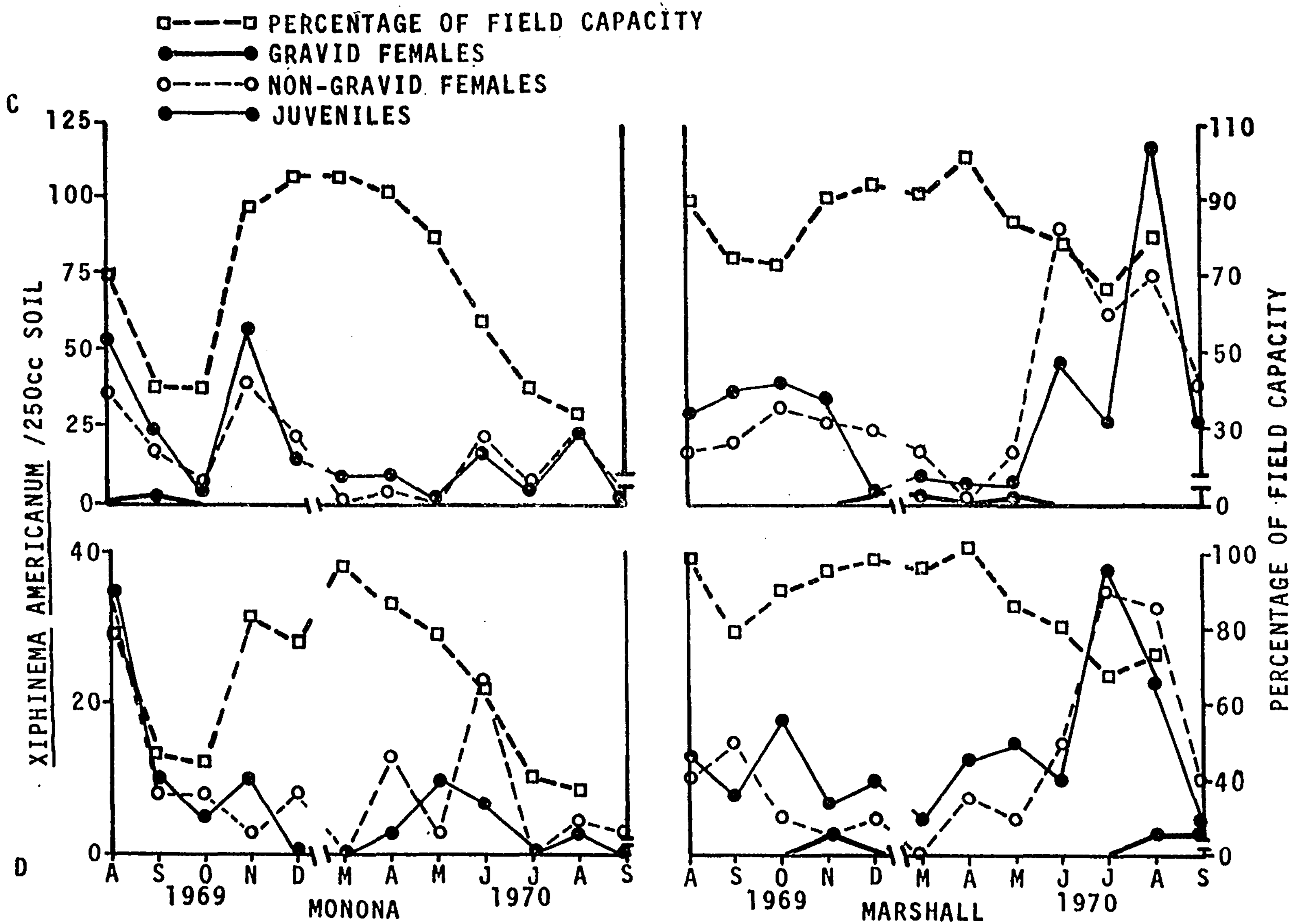
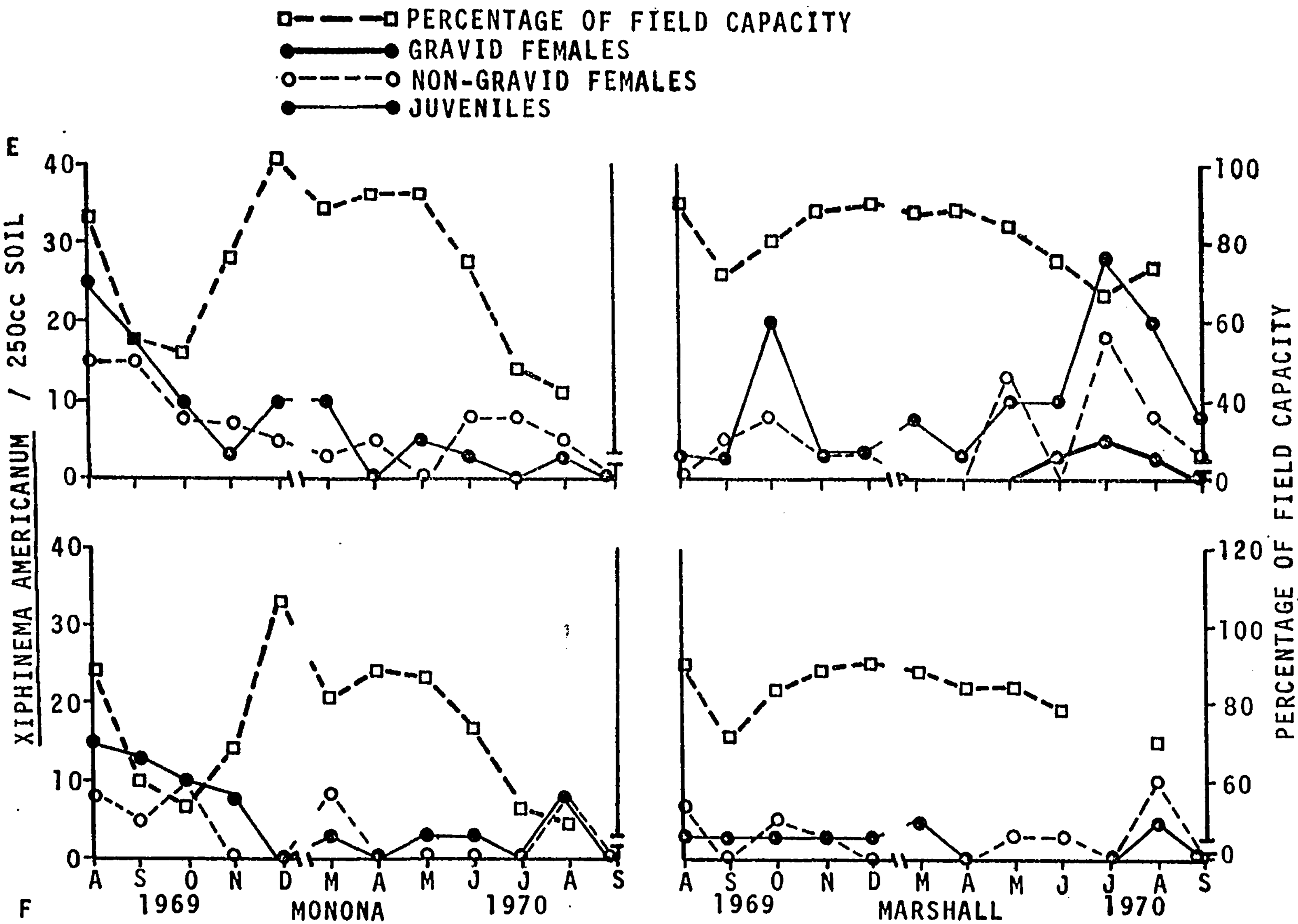

PERCENTAGE OF FIELD CAPACITY
GRAVID FEMALES
NON-GRAVID FEMALES
JUVENILES
C
D
XIPHINEMA AMERICANUM /250cc SOIL
PERCENTAGE OF FIELD CAPACITY
125
100
75
50
25
0
40
20
110
90
70
30
80
60
A S O N D M A M J J A S
1969
1970
MONONA
MARSHALL

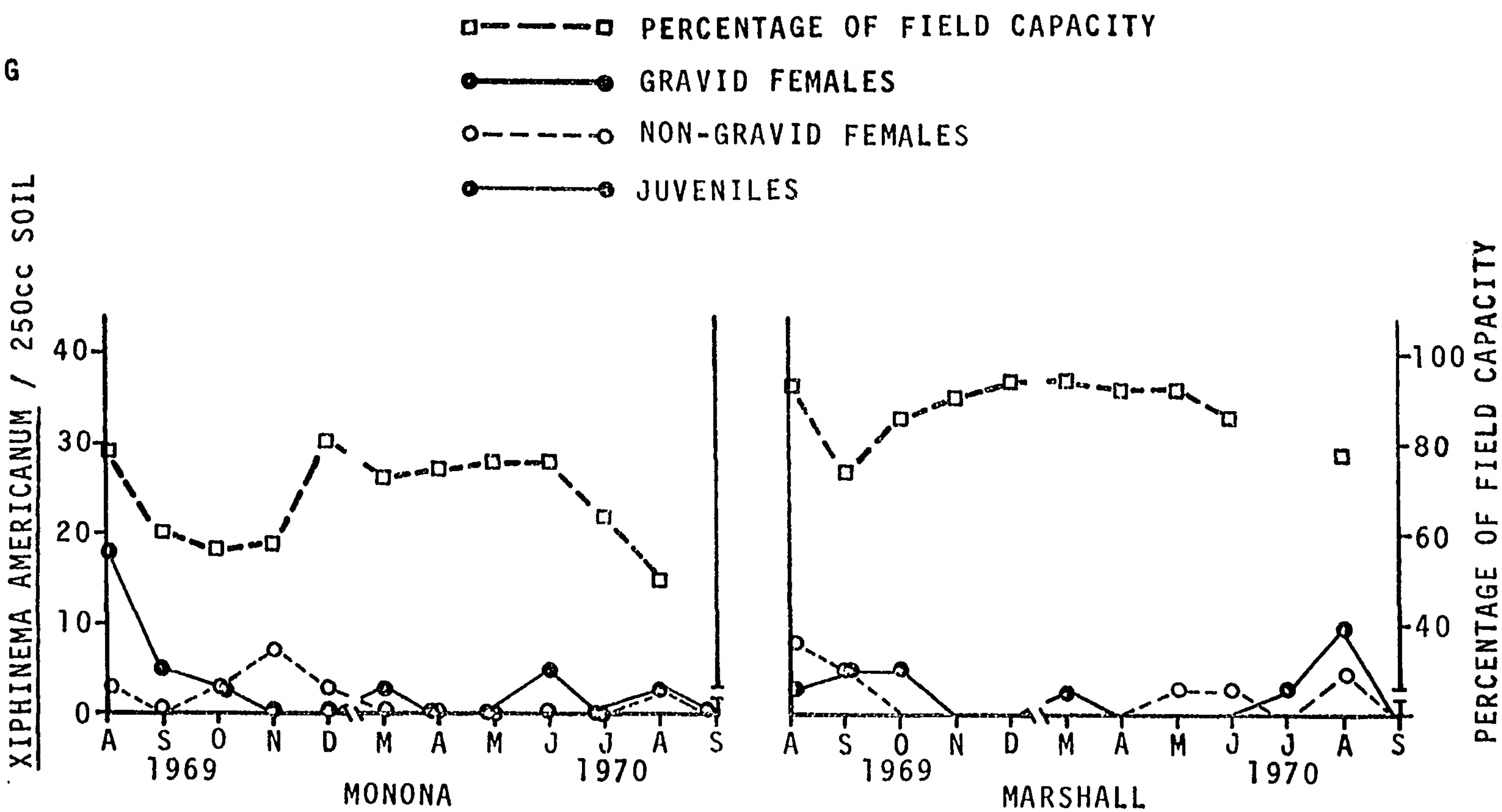
Fig. 5. (Continued)



PERCENTAGE OF FIELD CAPACITY
GRAVID FEMALES
NON-GRAVID FEMALES
JUVENILES
E
F
XIPHINEMA AMERICANUM / 250cc SOIL
PERCENTAGE OF FIELD CAPACITY
0
10
20
30
40
60
80
100
120
A S O N D M A M J J A S
1969
MONONA
1970
MARSHALL

Fig. 5. (Continued)

G



PERCENTAGE OF FIELD CAPACITY
GRAVID FEMALES
NON-GRAVID FEMALES
JUVENILES
XIPHINEMA AMERICANUM / 250cc SOIL
PERCENTAGE OF FIELD CAPACITY
0
10
20
30
40
60
80
100
A S O N D M A M J J A S
1969
1970
MONONA
MARSHALL

when numbers of *X. americanum* decreased and the ratio usually decreased when nematode numbers increased (Fig. 6, A-C). The adult to juvenile ratio of *X. americanum* in the Monona soil tended to increase throughout 1970 even though the ratio fluctuated (Fig. 6, A-B). The numbers of *X. americanum* were much smaller in the Monona than in the Marshall soil during the final 5 months, a period when the Monona soil was usually less than 50% of field capacity (Fig. 5, A-C). The Marshall soil received adequate precipitation to maintain a field capacity above 50%. The adult to juvenile ratio generally increased when the percentage of field capacity decreased and vice versa. This indicates that moisture is possibly important in at least partially governing adult to juvenile ratios.

Gravid females were found only in the top 15 inches of the Marshall soil with greatest numbers occurring in the top 6 inches. They were not found below 6 inches in the Monona soil (Fig. 5, A-G, Table 4 appendix). Gravid females were recovered at most sampling dates in the Marshall soil. One peak occurred in June which was followed by a larger one in August. Gravid females were rarely found in the Monona soil with most occurring in June.

Vertical Distribution of *Xiphinema americanum* in Monona Silt Loam and Marshall Silty Clay Loam

Most *X. americanum* were recovered from the top 6 inches in both soil profiles which was the area of greatest root concentration. Numbers generally decreased with increasing depth. Few nematodes were recovered below 12 inches (Fig. 3, 7, A-L, Table 3 appendix). Numbers of *X. americanum* decreased as the root weight decreased within a profile, but there was

Fig. 6. Adult to juvenile ratio of <u>Xiphinema americanum</u> around President Lincoln lilac roots in Monona silt loam and Marshall silty clay loam soils at Hamburg and Shenandoah, Iowa, respectively, from August 1969 through September 1970

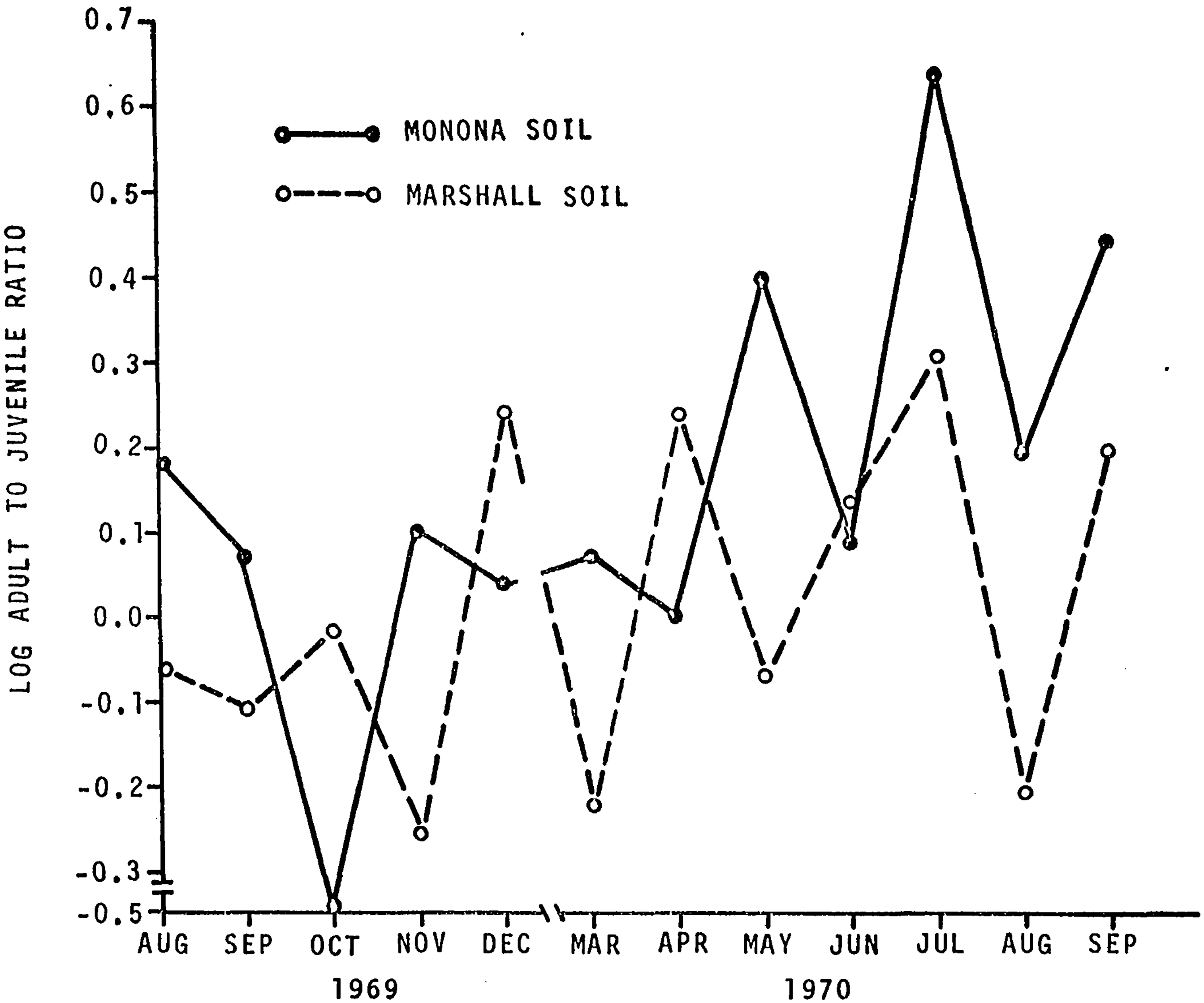

MONONA SOIL
MARSHALL SOIL
LOG ADULT TO JUVENILE RATIO
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.5
AUG
SEP
OCT
NOV
DEC
MAR
APR
MAY
JUN
JUL
AUG
SEP
1969
1970

Fig. 6. (Continued)

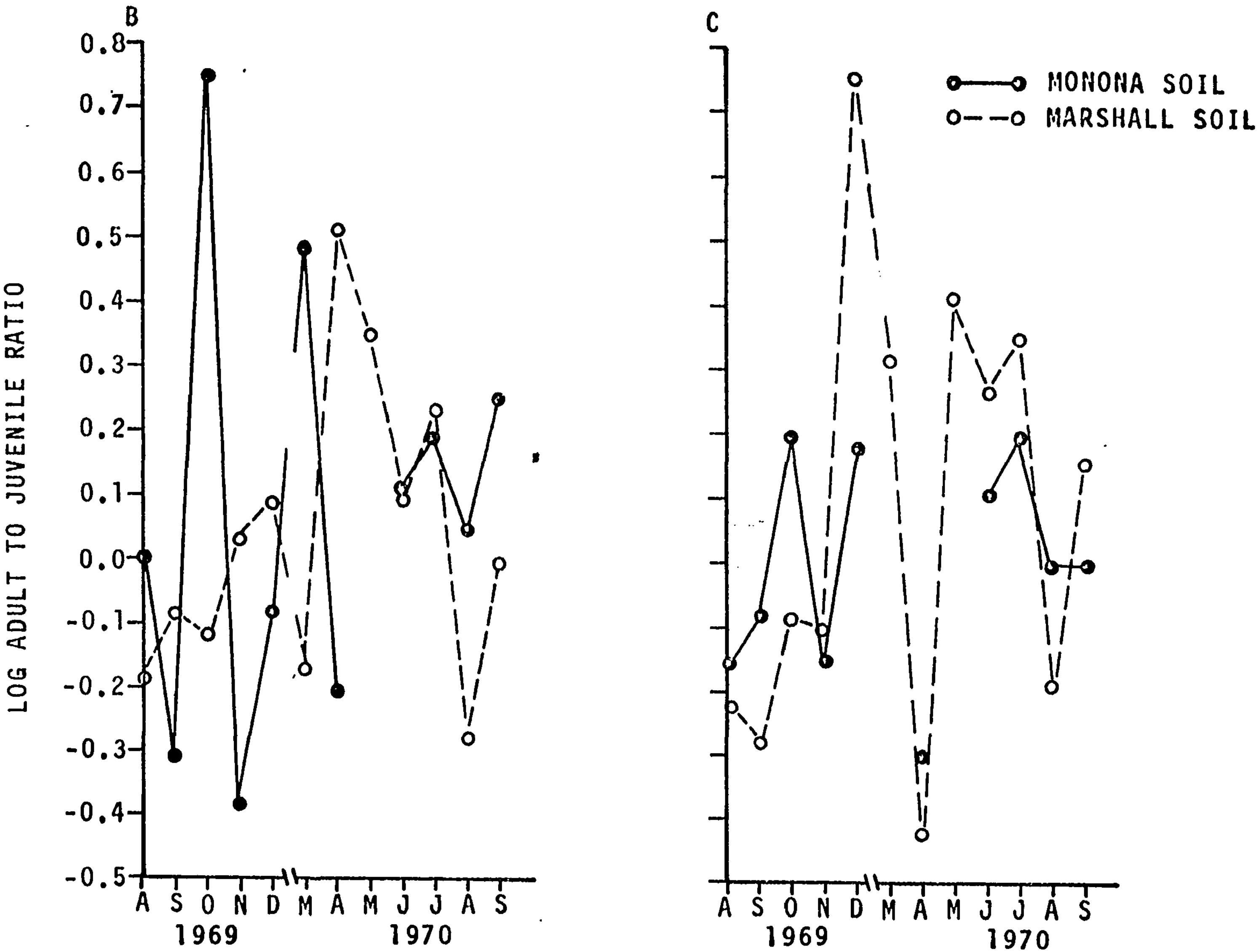

B
C
LOG ADULT TO JUVENILE RATIO
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
A S O N D M A M J J A S
1969
1970
MONONA SOIL
MARSHALL SOIL

Fig. 7. Depth distribution of _Xiphinema americanum_ and President Lincoln lilac roots in Monona silt loam and Marshall silty clay loam soil at Hamburg and Shenandoah, Iowa, respectively. A. August 1969; B. September 1969; C. October 1969; D. November 1969; E. December 1969; F. March 1970; G. April 1970; H. May 1970; I. June 1970; J. August 1970; K. September 1970. Level 1 = 0-3 inches; level 2 = 3-6 inches; level 3 = 6-9 inches; level 4 = 9-12 inches; level 5 = 12-15 inches; level 6 = 15-18 inches and; level 7 = 18-24 inches

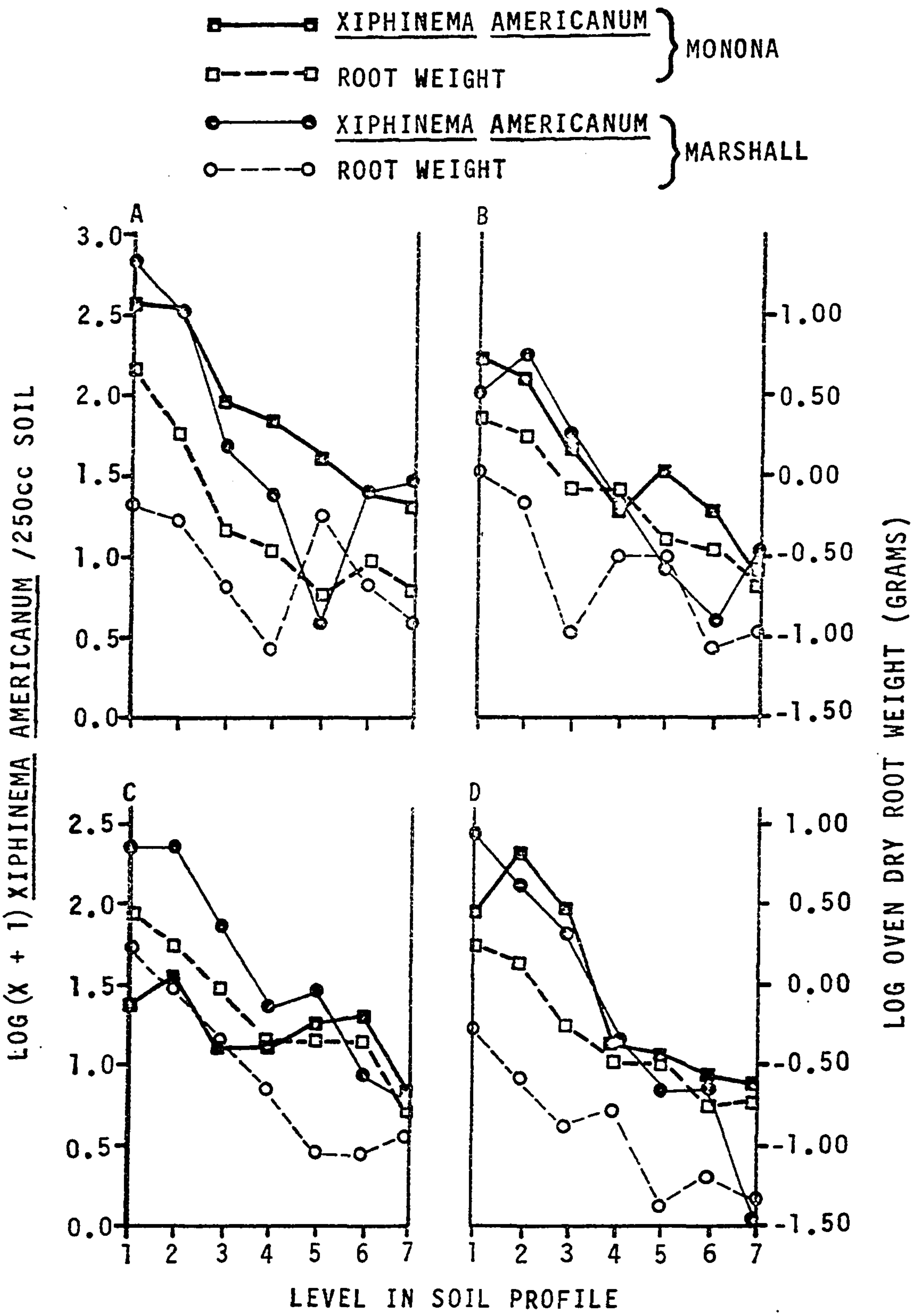

XIPHINEMA AMERICANUM
ROOT WEIGHT
MONONA
XIPHINEMA AMERICANUM
ROOT WEIGHT
MARSHALL
A
B
C
D
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1.00
0.50
0.00
-0.50
-1.00
-1.50
LOG (X + 1) XIPHINEMA AMERICANUM /250cc SOIL
LOG OVEN DRY ROOT WEIGHT (GRAMS)
1 2 3 4 5 6 7
LEVEL IN SOIL PROFILE

Fig. 7. (Continued)

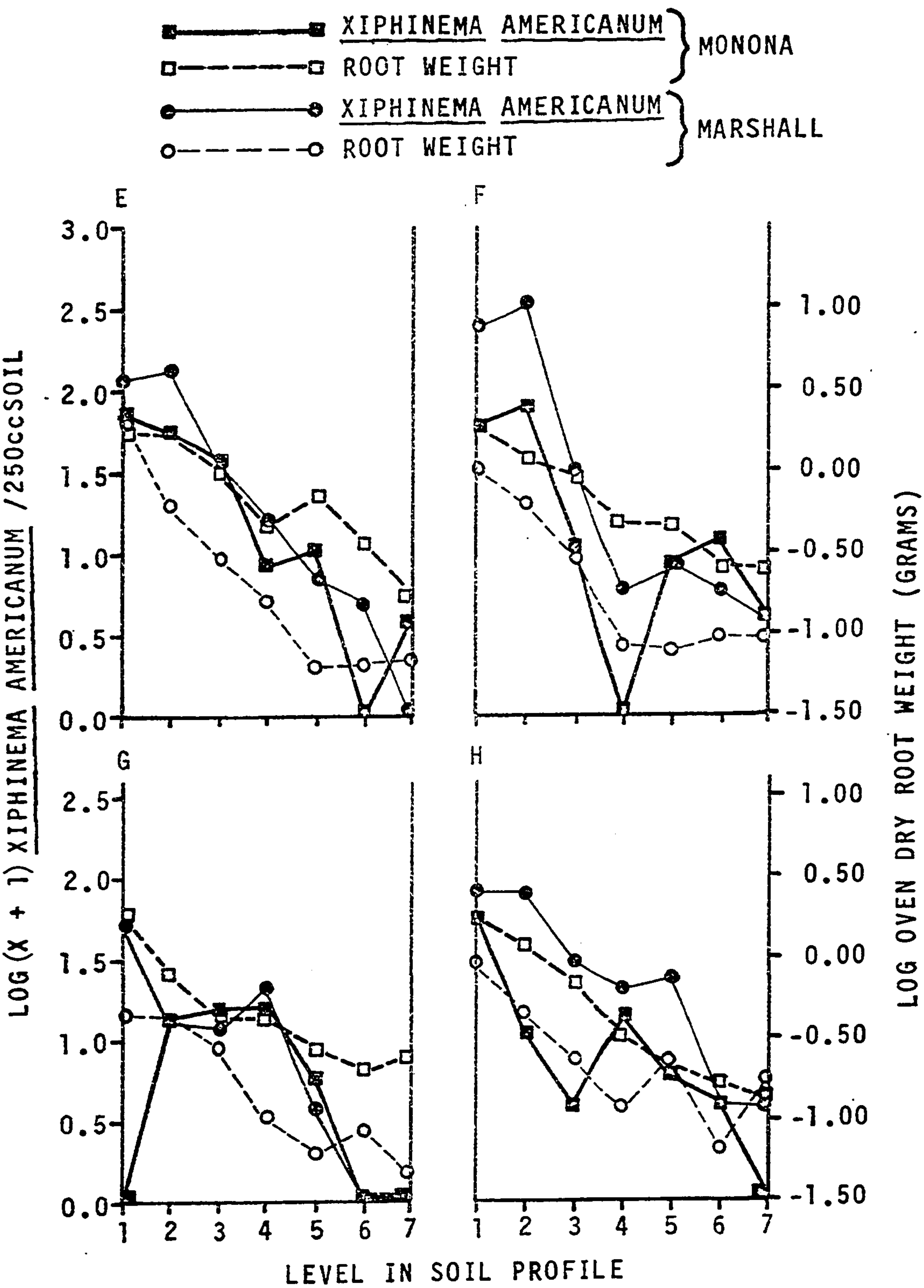
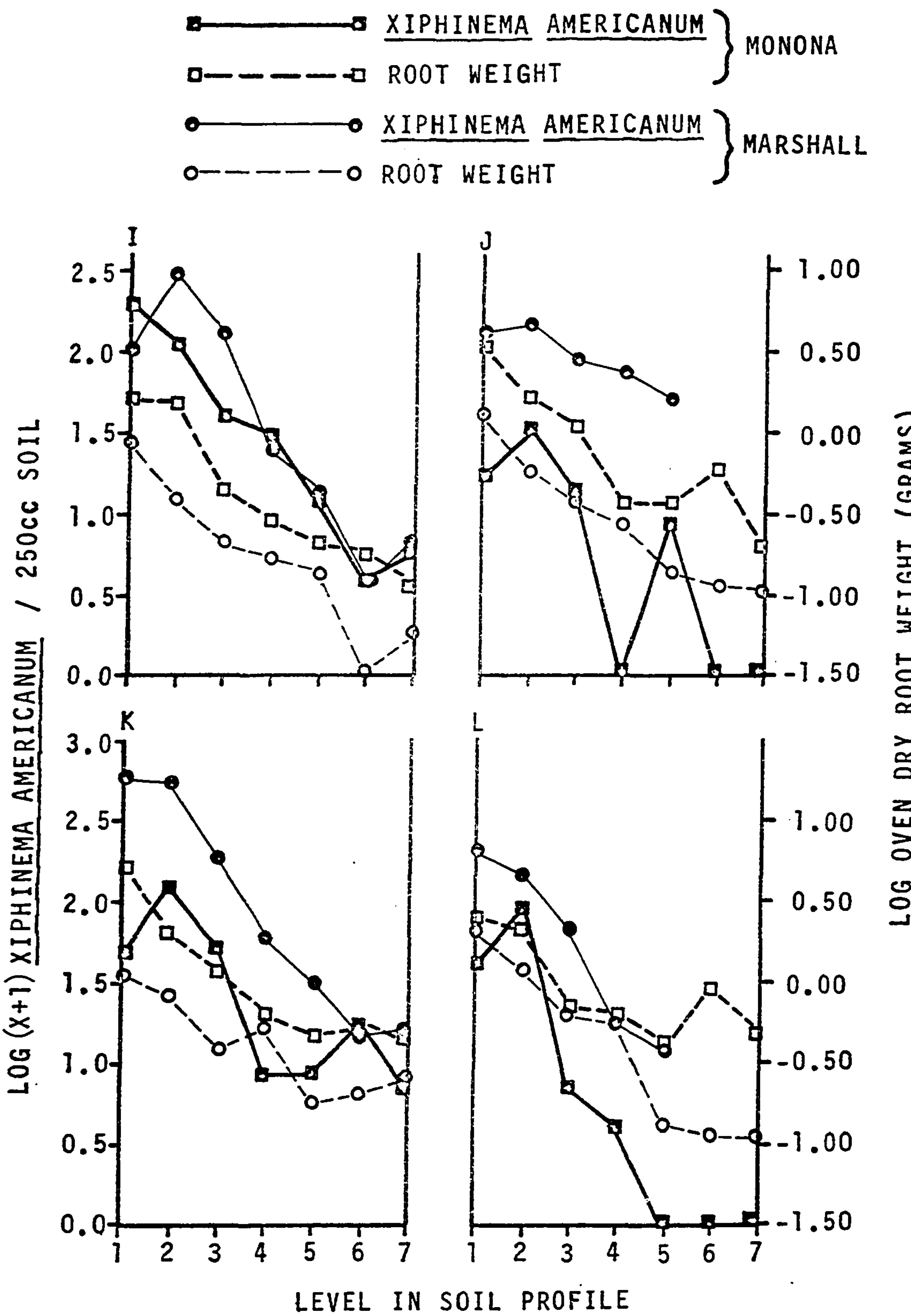

XIPHINEMA AMERICANUM
ROOT WEIGHT
MONONA
XIPHINEMA AMERICANUM
ROOT WEIGHT
MARSHALL
E
F
G
H
LOG (X + 1) XIPHINEMA AMERICANUM /250ccSOIL
LOG OVEN DRY ROOT WEIGHT (GRAMS)
LEVEL IN SOIL PROFILE

Fig. 7. (Continued)


XIPHINEMA AMERICANUM
ROOT WEIGHT
MONONA
XIPHINEMA AMERICANUM
ROOT WEIGHT
MARSHALL
I
J
K
L
LOG (X+1) XIPHINEMA AMERICANUM / 250cc SOIL
LOG OVEN DRY ROOT WEIGHT (GRAMS)
LEVEL IN SOIL PROFILE

no correlation of nematodes with root weight over all dates and depths. Root weights were greater in the Monona than in the Marshall soil but the numbers of *X. americanum* were usually greater in the Marshall than the Monona soil. Numbers of juveniles, gravid, and non-gravid adults, over all depths and dates, were significantly different (0.01 level) from each other in the two soils (Tables 4-6 appendix).

Temperatures at a given depth were similar to each other in the two soils, and for practical purposes, they were identical (Fig. 4). Thus, this factor would not account for differences in numbers of *X. americanum* populations at the two sites, especially in the top 6 inches of soil. Soil moistures were different at various dates, especially in 1970, when the Marshall soil received adequate precipitation while the Monona soil did not. This difference in moisture may partially account for differences in nematode numbers during the drier periods. Soil moisture for the two sampling sites were similar during the first few samplings, however, and the Monona soil contained fewer *X. americanum* than did the Marshall soil. Even though population fluctuations followed similar patterns in the two soils, the adult to juvenile ratio behavior was antithetical until late in the experiment when water tensions were most dissimilar (Fig. 6, A-C), i.e. the Monona soils had a high water tension and the Marshall soils had a low water tension (Fig. 5, A-L).

The adult to juvenile ratio was different in each of the soils at a given date (Fig. 8, A-L). For example, a greater proportion of adults were in the 0-3 inch level of the Monona soil than the Marshall soil, but the converse occurred at the lower two levels for August 1969 (Fig. 8, A). The ratios were parallel to each other during some months through several

Fig. 8. Adult to juvenile ratio of *Xiphinema americanum* around President Lincoln lilac roots by depth in the Monona silt loam and the Marshall silty clay loam soils at Hamburg and Shenandoah, Iowa, respectively. A. August 1969; B. September 1969; C. October 1969; D. November 1969; E. December 1969; F. March 1970; G. April 1970; H. May 1970; I. June 1970; J. July 1970; K. August 1970; L. September 1970. Level 1 = 0-3 inches; level 2 = 3-6 inches; level 3 = 6-9 inches; level 4 = 9-12 inches; level 5 = 12-15 inches; level 6 = 15-18 inches and; level 7 = 18-24 inches

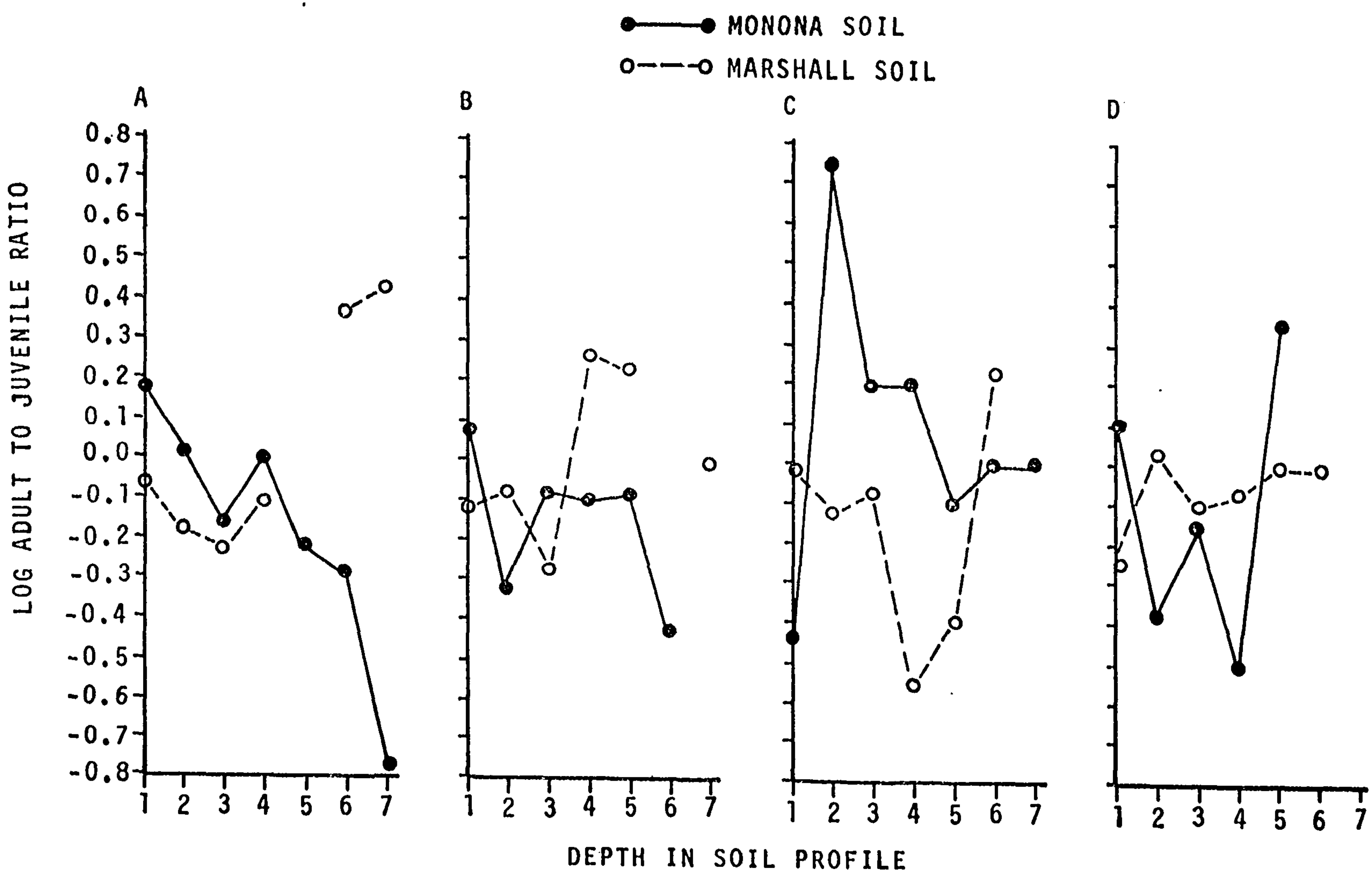

MONONA SOIL
MARSHALL SOIL
A
B
C
D
LOG ADULT TO JUVENILE RATIO
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
1 2 3 4 5 6 7
DEPTH IN SOIL PROFILE

Fig. 8. (Continued)

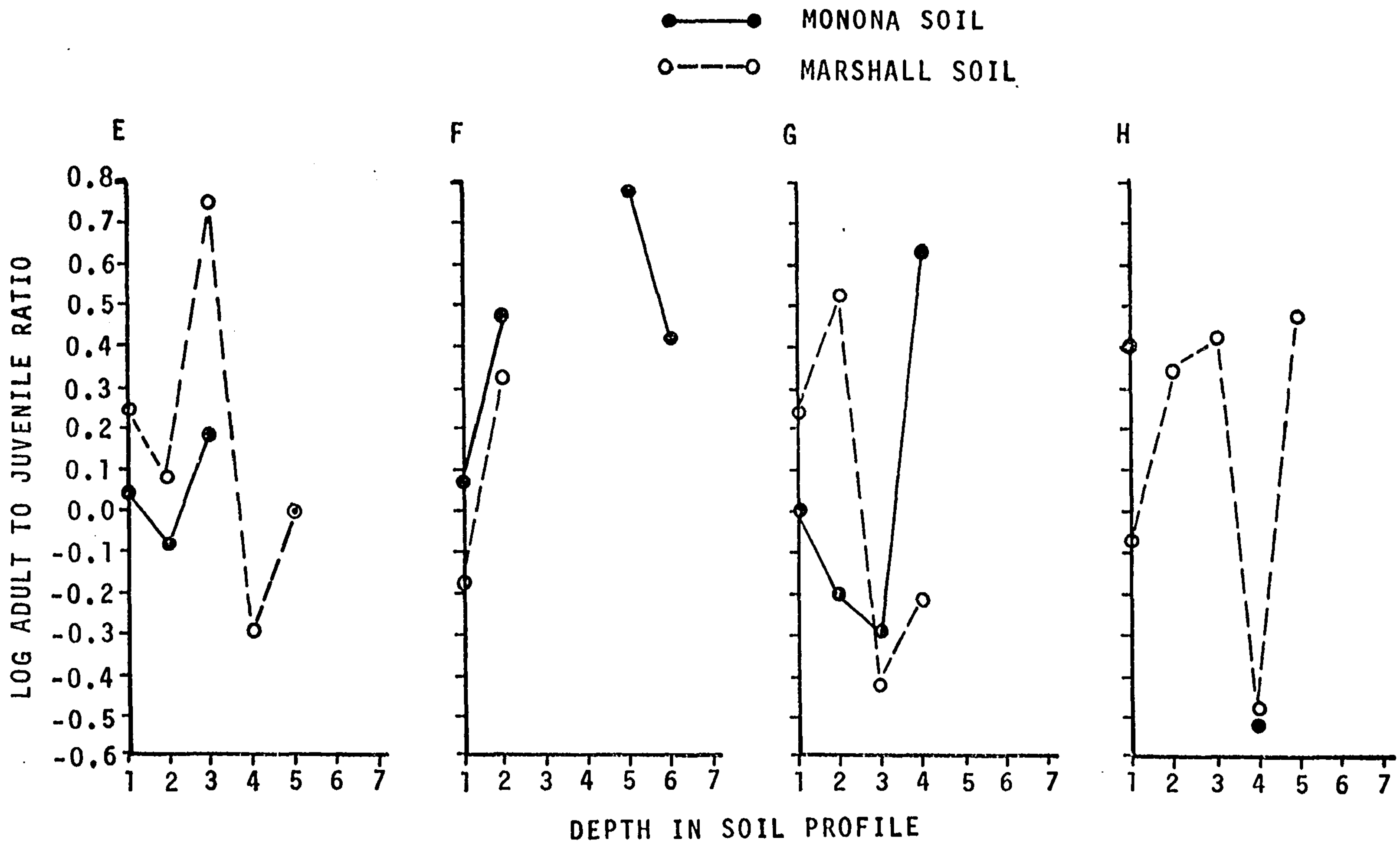
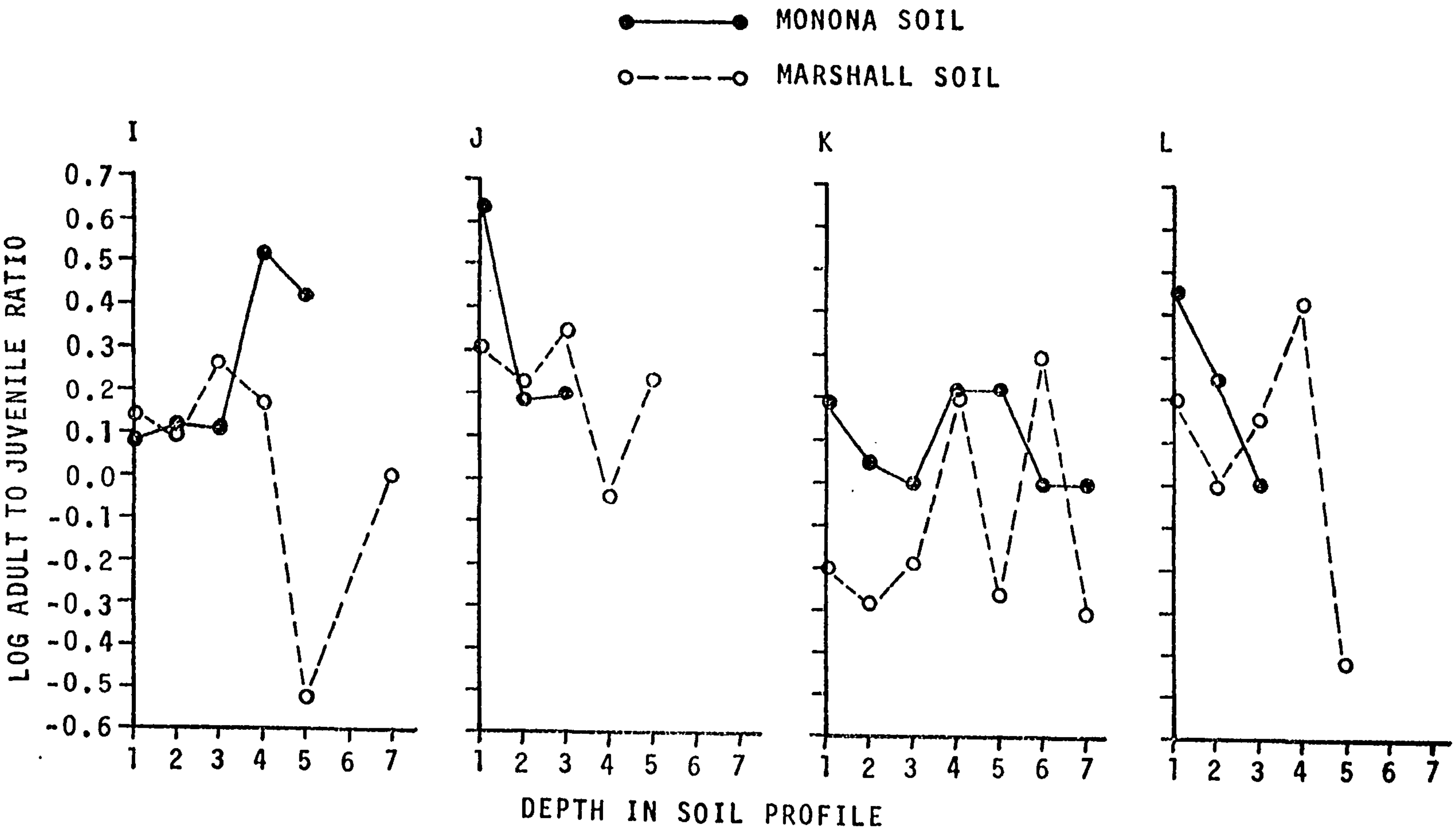

MONONA SOIL
MARSHALL SOIL
E
F
G
H
LOG ADULT TO JUVENILE RATIO
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
1 2 3 4 5 6 7
DEPTH IN SOIL PROFILE

Fig. 8. (Continued)


MONONA SOIL
MARSHALL SOIL
I
J
K
L
LOG ADULT TO JUVENILE RATIO
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
1 2 3 4 5 6 7
DEPTH IN SOIL PROFILE

levels (Fig. 8, A, E, F), i.e. the adult to juvenile ratio changed in a similar manner with depth.

Relationship of *Xiphinema americanum* to Soil Moisture and Temperature

Nematodes were found in greatest numbers at all levels in the soil profile during the growing season. The size of nematode population was variously related to soil moisture and temperature. Soil moisture at 60% of field capacity appeared to be a critical point for survival and reproduction of *X. americanum*. Numbers of *X. americanum* increased when the soil moisture was above this percentage providing that soil temperature was not inhibiting. Soil temperature during the autumn and winter seasons appeared to limit population size. Nematode numbers decreased as temperatures decreased from yearly maximums even though soil moisture was equivalent to that when population peaks were attained in August. Numbers of *X. americanum* generally increased as soil temperature increased throughout the growing season, but the nematode fluctuations coincided with moisture fluctuations. Populations were small in April even though the soil moisture was greater than 90% of field capacity at all levels. The top level was the wettest being 108% and 120% of field capacity in the Marshall and Monona soils, respectively. Soil temperatures frequently were slightly less than 0 C at 8:00 A.M. and as much as 8 C by 5:00 P.M.

Populations in both the Marshall and Monona soils began to increase when minimum temperatures remained above 5 C and they generally continued to increase until August if soil moisture was greater than 60% of field capacity (Fig. 5, A-C). As soil moisture increased above 60% of field capacity, populations became larger (Fig. 5, A-D).

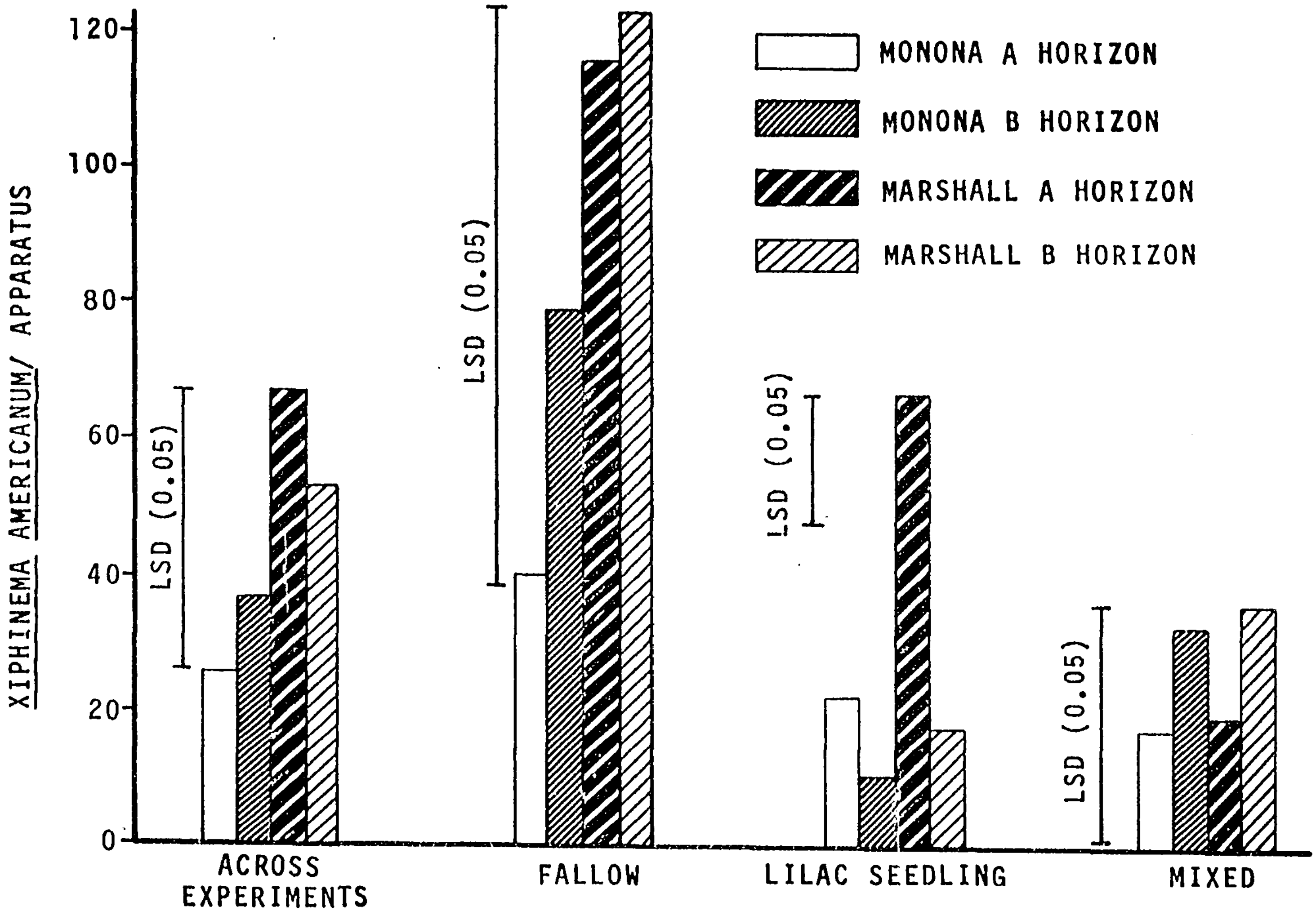
Based upon evidence presented in Fig. 3-6, greatest molting and development began to occur when soil temperatures were between 10-15 C. The greatest population development occurred when the average daily soil temperature was 20-30 C. Maximum numbers of gravid females corresponded with these high temperatures, although many gravid females occurred in June when the average daily soil temperatures were 15-25 C.

Survival and Migration of Xiphinema americana in the A and B Horizon Soils of the Monona Silt Loam and the Marshall Silty Clay Loam Soils

Field data provided clues that some factor or factors in the Monona soil inhibited survival of X. americanum as compared with that in the Marshall soil. Experiments using soil columns (Fig. 2) in the growth chamber were designed to test this hypothesis. The results obtained for the effect of soil type and soil horizon on the survival of X. americanum are presented in Fig. 9. Survival was greater in the Marshall soil for both the A and B horizons in the fallow treatment. Survival in the fallow treatment increased as percentage clay and cation exchange capacity increased, and as soluble salts and pH decreased. Survival in the Marshall and Monona soils was greater when a host was used and significantly greater (0.05 level) in the Marshall soil under alternating temperature (Fig. 10). In the lilac seedling experiment, survival in the Marshall A horizon was significantly greater (0.05 level) when compared with that in other horizons of both soils (Fig. 9).

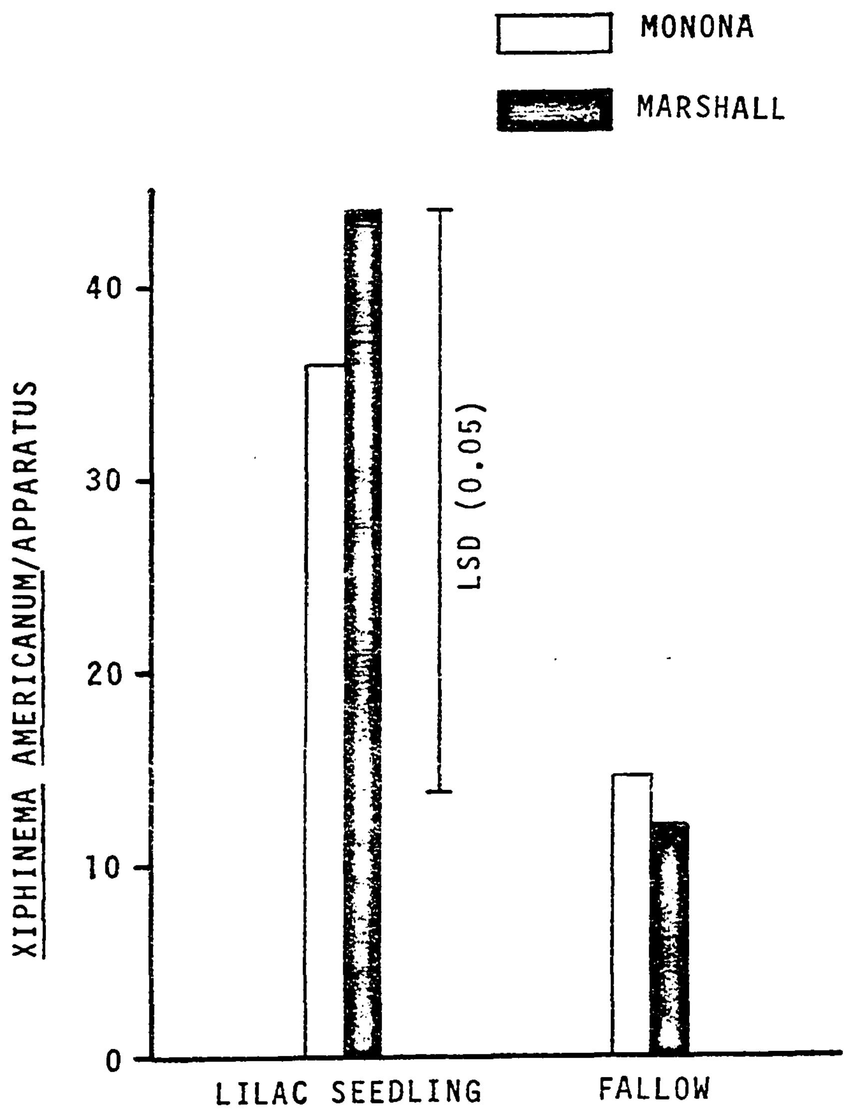
Greater numbers of X. americanum were recovered in Experiment 1 (fallow) than in Experiment 2 (lilac seedling). The inoculum in Experiment 1 was about two times greater and the duration was one-half as long

Fig. 9. Survival of *Xiphinema americanum* in 6 inch soil columns containing Monona silt loam and Marshall silty clay loam A and B horizon soils



XIPHINEMA AMERICANUM/ APPARATUS
0
20
40
60
80
100
120
LSD (0.05)
LSD (0.05)
LSD (0.05)
LSD (0.05)
MONONA A HORIZON
MONONA B HORIZON
MARSHALL A HORIZON
MARSHALL B HORIZON
ACROSS EXPERIMENTS
FALLOW
LILAC SEEDLING
MIXED

Fig. 10. Survival of Xiphinema americanum in 6 inch soil columns containing Monona silt loam and Marshall silty clay loam A and B horizon soils with lilac seedling or fallow treatment


MONONA
MARSHALL
XIPHINEMA AMERICANUM/APPARATUS
40
30
20
10
0
LSD (0.05)
LILAC SEEDLING
FALLOW

as that of Experiment 2. The nematodes that survived in Experiment 2 (lilac seedling) were active and their intestines were full of food particles. Intestines of nematodes in Experiment 1 (fallow) were vacuolated and most of the nematodes were dead. This phenomenon was also observed in Experiment 3 where both lilac seedlings and fallow treatments were used.

Diurnal alternating temperature of 13-24 C was beneficial for survival of X. americanum in the Marshall soil but did not significantly affect X. americanum in the Monona soils in the fallow treatment. Survival of X. americanum in the Marshall soil horizons did not differ significantly when lilac seedlings were used, but greatest survival occurred in the alternating temperature (18-32 C), and was significantly greater than in the Monona soils receiving the same temperature treatment (Fig. 11).

Migration patterns were affected by a host and differed in the various soil horizons (Fig. 12-13). When X. americanum were placed at the 3 inch level in the fallow soil columns, the nematodes migrated downward in the Monona B horizon and Marshall A and B horizons, but there was upward migration in the Monona A horizon. When a lilac was present, migration in the Monona A and Marshall B horizons was random, but was upward in the Monona B and Marshall A horizons.

Relationship of Xiphinema americanum Numbers with Soil Factors

Regression of X. americanum numbers with soil factors (Table 2) and oven dry root weight was made removing the effects of blocks and depths (Tables 7-8 appendix). The R^2 (coefficient of determination) of 68% and

Fig. 11. Effect of constant and alternating temperature on survival of *Xiphinema americanum* in 6 inch soil columns containing Monona silt loam and Marshall silty clay loam A and B horizon soils

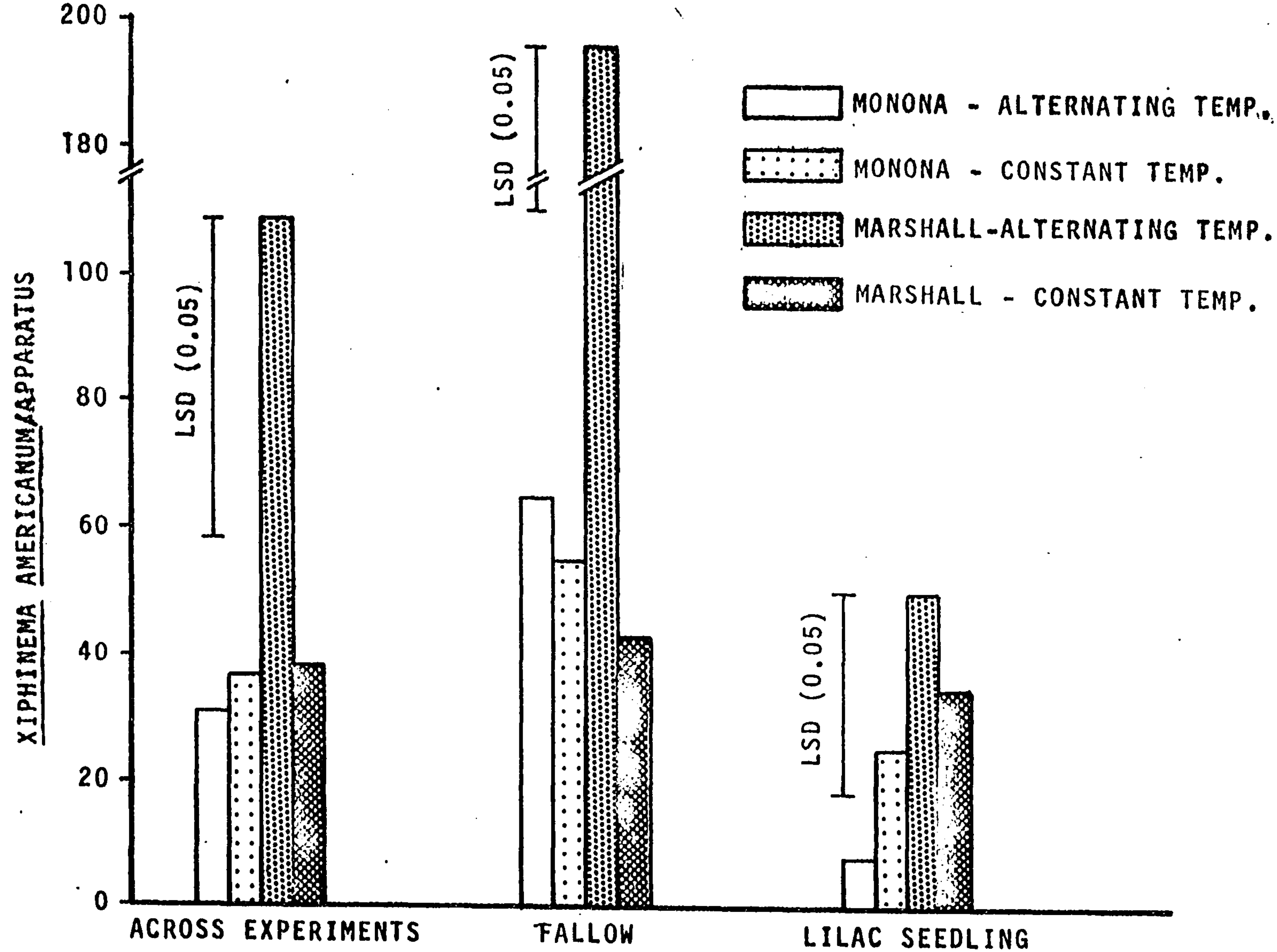

XIPHINEMA AMERICANUM/APPARATUS
200
180
100
80
60
40
20
0
LSD (0.05)
LSD (0.05)
LSD (0.05)
MONONA - ALTERNATING TEMP.
MONONA - CONSTANT TEMP.
MARSHALL-ALTERNATING TEMP.
MARSHALL - CONSTANT TEMP.
ACROSS EXPERIMENTS
FALLOW
LILAC SEEDLING

Fig. 12. Distribution of *Xiphinema americanum* in 6 inch soil columns containing Monona silt loam and Marshall silty clay loam A and B horizon soils. Aliquots of 600 and 320 nematodes were placed at the 3 inch level at the beginning of the experiments in the fallow and lilac seedling treatments, respectively

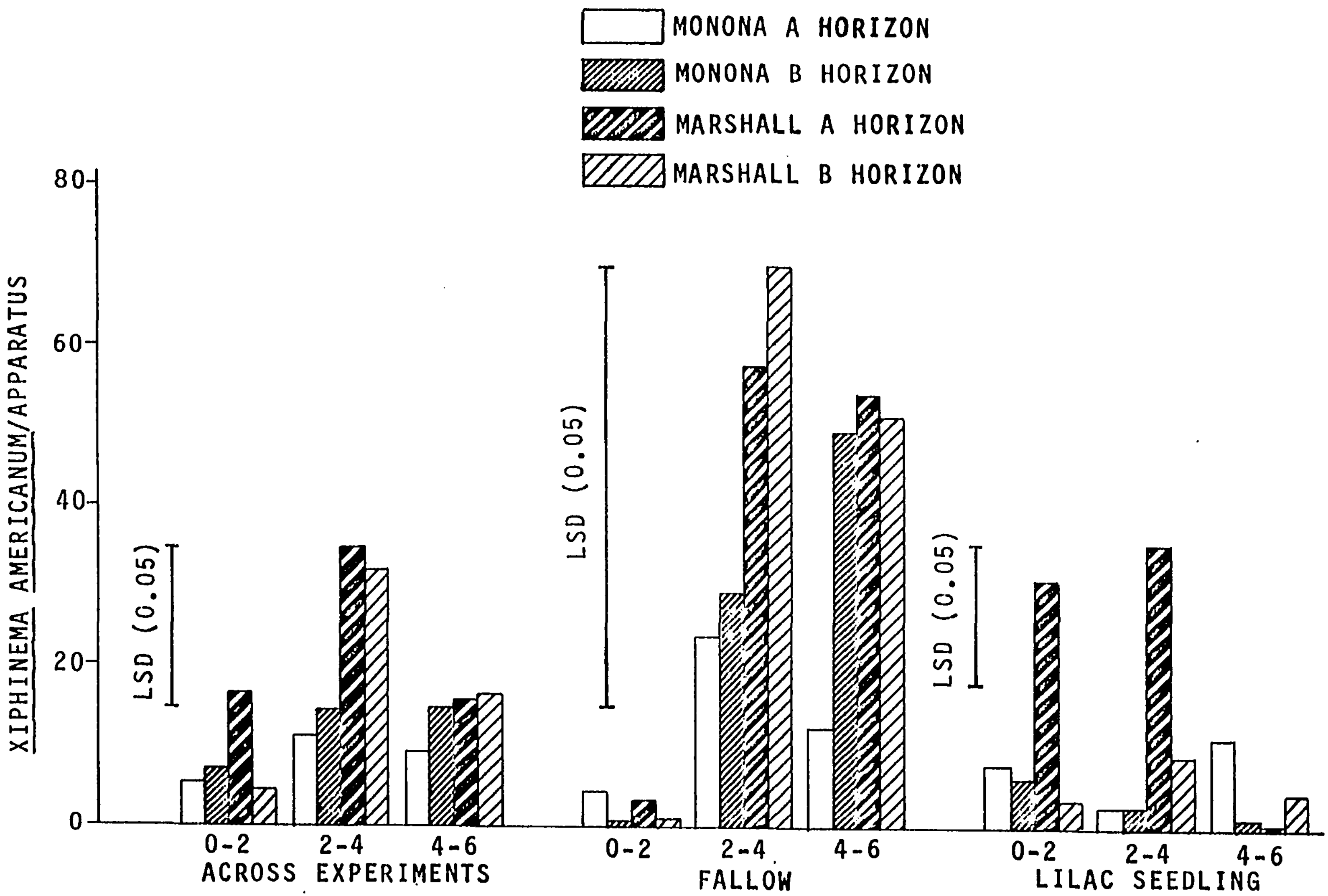
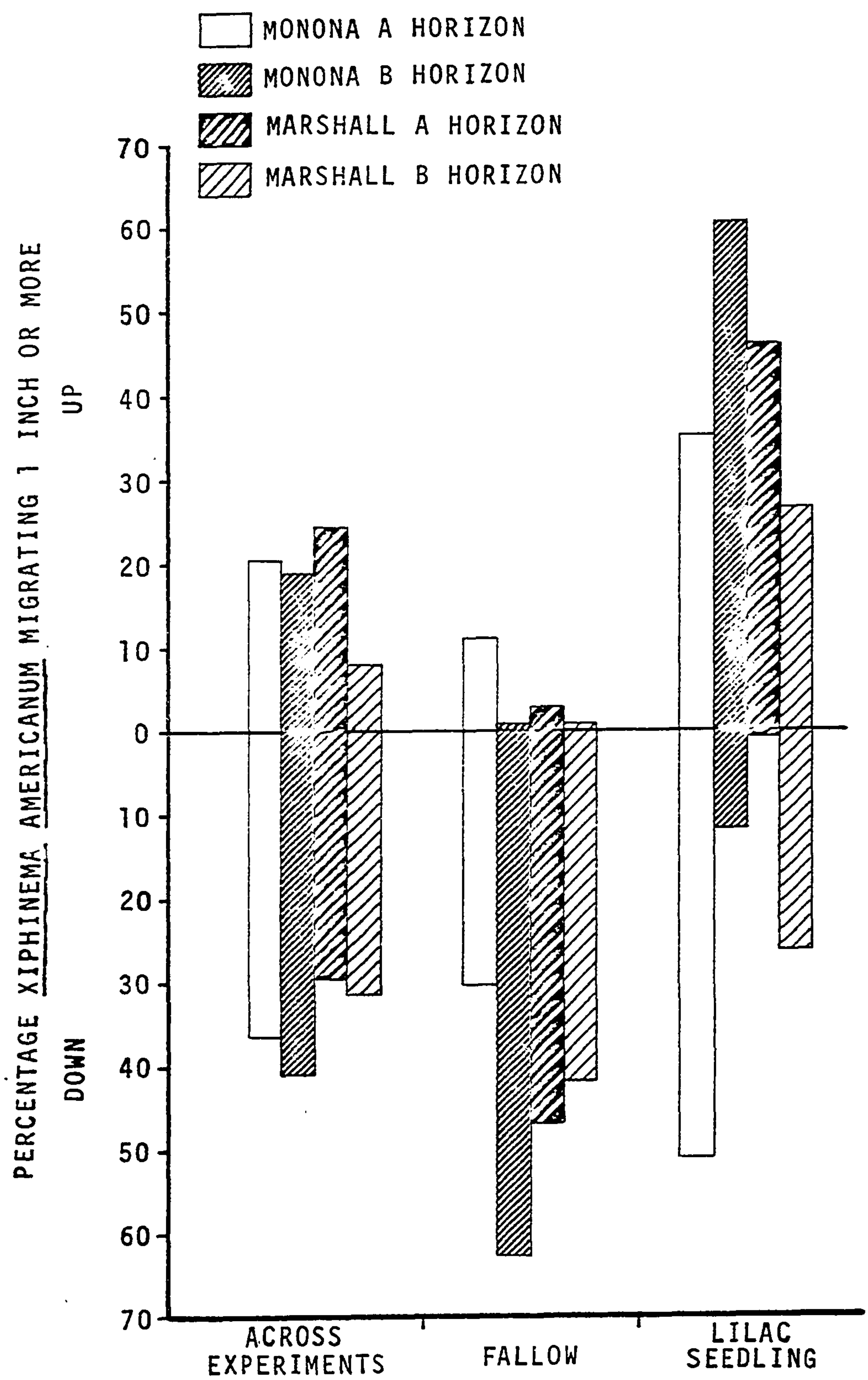

MONONA A HORIZON
MONONA B HORIZON
MARSHALL A HORIZON
MARSHALL B HORIZON
XIPHINEMA AMERICANUM/APPARATUS
0
20
40
60
80
LSD (0.05)
LSD (0.05)
LSD (0.05)
0-2
2-4
4-6
ACROSS EXPERIMENTS
0-2
2-4
4-6
FALLOW
0-2
2-4
4-6
LILAC SEEDLING

Fig. 13. Percentage *Xiphinema americanum* migrating vertically at least one inch in 6 inch soil columns containing Monona silt loam and Marshall silty clay loam A and B horizon soils


MONONA A HORIZON
MONONA B HORIZON
MARSHALL A HORIZON
MARSHALL B HORIZON
PERCENTAGE XIPHINEMA AMERICANUM MIGRATING 1 INCH OR MORE
UP
DOWN
70
60
50
40
30
20
10
0
10
20
30
40
50
60
70
ACROSS EXPERIMENTS
FALLOW
LILAC SEEDLING

80% are the per cent reduction in the sum of squares of X. americanum attributable to the combined effects of the 13 soil factors and oven dry root weights for the Monona and Marshall soils, respectively. The factors in both soils which contribute most to R^2 are root weight, percentage water at field capacity, percentage organic matter, and soluble salts. The factor which contributed most to R^2 in the Monona soil but not the Marshall soil was percentage sand. Factors which contributed most to R^2 in the Marshall but not the Monona soil were percentage silt, cation exchange capacity, and ammonium.

All soil factors measured except per cent organic matter, total nitrogen, and ammonium were significantly different between the Monona and Marshall soils. The texture of the Marshall A horizon has much less clay than the Marshall B horizon, consequently, it is difficult to seperate factors that are not related to texture. The Monona A and B horizons are identical in texture. The only factors that were significantly different between these two horizons were cation exchange capacity, nitrate nitrogen, and phosphorus. The differences in survival and migration of X. americanum could possible be directly or indirectly related to these factors within the Monona soils. These factors may also contribute to the differences in nematode numbers observed in the field experiment.

DISCUSSION

Data obtained from the growth chamber experiments support the conclusion that properties of the Marshall soil are more suitable for establishment and survival of *X. americanum* than are those of the Monona soil. Many studies have revealed that nematodes differ in soils of different types (4, 6, 9, 10, 21, 24, 25, 32, 43, 44, 46, 48). Most reports indicate that texture and structure are the important factors relative to nematode populations. Results from the laboratory experiments reported here indicate that factors other than texture were of importance in the Monona and Marshall soils because nematode survival and migration were different in the Monona A and B horizons. Contradictions in the literature with regard to texture (4, 24, 43) possibly reflect a soil factor or factors which dominate over texture; or might be due to different soil structures (45).

The greater numbers of *X. americanum* in the Marshall soil in the field experiment undoubtedly was partially due to soil moisture since the Monona soil was often drier. Survival may have been reduced in the Monona soil columns because moisture in this soil was 50% greater than field capacity at the 0-2 inch level compared with field capacity at the same level in the Marshall soil. The moisture difference was apparently due to the greater capillary water movement in the Monona soil. Griffin and Barker (18) did not use moistures greater than field capacity, but found that hatching, development, and survival of *X. americanum* was reduced at 90% and 100% of field capacity. The water content of soil is related to aeration and may be the factor which affects *X. americanum* rather than soil water directly. Van Gundy *et al.* (42) found that the concentration of oxygen and its ability to diffuse through the soil pores was important to the survival of *X. americanum*. Oxygen diffusion would be reduced as soil water increased and possibly create adverse conditions for *X. americanum*.

Soil structure was not determined, but it should have been the same in both sites because plants influence the soil structure (2). Consequently, it would not cause the differences found in the soils.

Physical soil factors are undoubtedly important to the survival of *X. americanum*, but chemical factors might sometimes be more important as indicated by the differences obtained with the Monona A and B horizon soils which have identical textures and similar soil moistures. All soil factors measured except organic matter, total nitrogen, and ammonium were significantly different between the two soils. Cation exchange capacity, nitrate nitrogen, and phosphorus were the only soil factors measured which were significantly different between the Monona A and B soil horizons (Table 2). Any effect of cation exchange capacity, since pH and organic matter were not significantly different, and textures were identical in the Monona A and B soil horizons, is probably related to the ions on the exchange site rather then the direct effect of cation exchange capacity. Various cations that were not measured such as calcium and magnesium might have an influence on *X. americanum*. Phosphorus and some other anions are involved on exchange sites. Nitrate nitrogen is predominantly in the soil solution. These ions could be factors in the observed behavior of *X. americanum* in the Monona A and B horizons and may directly or indirectly affect the ability of *X. americanum* to attain greater numbers in the Marshall than Monona soils.

The greater salt concentration in the Monona soil may be important in retarding *X. americanum* development and reproduction. Nematodes vary in their sensitivity to salt concentration, and possibly *X. americanum* is salt sensitive although there is no proof of this. Salt concentrations of 0.3 M or greater inhibited hatching of *H. rostochiensis* Wollenweber and *Meloidogyne arenaria* (Neal) Chitwood (8). Feder (11) suggested that free-living nematodes in sucrose and glucose solutions were killed by exosmosis at osmotic pressures equivalent to the permanent wilting point of plants. This type of reaction may have reduced *X. americanum* in late 1970 in the Monona soil and may be a factor in the difference of population in the two soils.

Differences in migration in the Monona soil, which has a homogenous texture throughout the profile, further indicates that factors other than texture are involved in nematode behavior. Nitrate nitrogen, phosphorus, and cation exchange capacity are known to influence plant growth, which could then affect *X. americanum*, possibly by greater plant resistance or susceptibility. Although the plant may be a factor, one or more soil properties are probably the important factors in this study. Plants were not used in Experiment 1 conducted in a growth chamber and the migration of *X. americanum* was significantly different. Evidently nitrate nitrogen, phosphorus, or cation exchange capacity, alone or in combination, or other factors not measured affect the behavior and survival of *X. americanum*. The antithetical behavior of the adult to juvenile ratios in the Monona and Marshall soil may be a consequence of the various edaphic factors such as those linked with cation exchange capacity. Such factors could conceivably mask the effects of texture, thus creating the apparently contradictory reports. Contradictions regarding nematode ecology may be resolved by further comparative nematode-edaphology research with similar soils, such as those used in this study. Edaphic factors, whether closely or remotely linked with texture, that affect X. americanum and other nematodes may be identified.

It is difficult to explain why the migration of X. americanum was oriented upward when a host was present and downward in the fallow treatments in soil columns in the Monona B horizon and not the Monona A horizon soils since they are both identical in texture. Where migration was vertically oriented, it may have been affected by carbon dioxide concentration. Rohde (33) suggested that carbon dioxide released from roots may act as an orthokenetical stimulus to decrease activity and prevented nematodes from leaving the root. In the present work, the bottom of the soil column would have a greater carbon dioxide concentration than the upper areas in the fallow soil and this may have acted on X. americanum in a similar manner. Whether carbon dioxide acts as an attractant to X. americanum is speculative until more experimentation is made.

Population fluctuations of X. americanum and occurrence of gravid females were similar in the two soils. These results agree with those of Norton (29) in that the highest peak occurred in August, but were dissimilar to those of Griffin and Darling (19), and Malek (27), who reported highest numbers in June and July. These differences could be due to dissimilar hosts and the manner by which the nematode responds to its environment.

Comprehensive knowledge of nematode biology would aid in the wise use of nematicides. Application of such knowledge could reduce the indiscriminate use of pesticides, thus saving both time and money. Length of the life cycle of *X. americanum* could not be determined from this study. It is probably at least one year because only one large peak occurred during the year. Malek (27) also suspected that the life cycle of *X. americanum* may require at least one year in South Dakota. If true, chemical control of this nematode would be most effective if the nematode population was reduced during its reproductive peaks in June and August. Proper timing of soil fumigation would reduce egg laying, thus decreasing the number of over-wintering forms. Few nematodes would be available to reproduce, and consequently the resulting population would be small.

SUMMARY

Experiments were designed to compare the behavior of *Xiphinema americanum* associated with *Syringa vulgaris* variety President Lincoln in Monona silt loam and Marshall silty clay loam soils. These are loess derived soils that are located in southwestern Iowa; the former is minimally developed and the latter is medially developed.

Numbers of *X. americanum* were significantly greater in the Marshall than in the Monona soil over all dates and depths. Adult to juvenile ratio changes were antithetical to each other in the Monona and Marshall soils throughout the experiment except when the water tensions were the most dissimilar. Factors other than host, oven dry root weight, and moisture differences were interpreted as being responsible for the observed population differences.

Numbers of *X. americanum* decreased as the root weight decreased in the soil profile. Greatest numbers of *X. americanum* occurred in the top 6 inches of soil and few were found below 12 inches.

Numbers of *X. americanum* generally increased or decreased simultaneously at all levels, with the maximum numbers occurring in August of both years in the Marshall soil and in August 1969 and June 1970 in the Monona soil. The fluctuation of juvenile and adult numbers were similar to each other. Greatest numbers of gravid females coincided with peaks of total *X. americanum* numbers. The population fluctuations were parallel to percentage of field capacity during the growing season. Numbers of *X. americanum* were low in winter although soil moistures were similar to those when population peaks were attained. The adult to juvenile ratios

increased when percentage of field capacity decreased and the ratio decreased when percentage of field capacity increased.

Migration of X. americanum occurred in soil columns in the laboratory but it was not evident in the field. Migration of X. americanum was the greatest and its greatest vertical orientation was in the Monona B and Marshall A horizon soils. Migration and survival were different in the identically textured Monona A and B horizon soils, indicating that a factor or factors other than texture may be important.

In laboratory experiments, survival of X. americanum was greater in the Marshall than Monona soils in the fallow treatment and significantly greater (0.05 level) in the Marshall A horizon over all other soils when lilac seedlings were used. Xiphinema americanum recovered from the fallow treatment had vacuolated intestines and most nematodes were dead whereas in lilac treatments, the intestines were full of food particles and the nematodes were active.

Oven dry root weight and 13 soil factors accounted for 68% and 80% (R^2) reduction in the sum of squares of X. americanum in the Monona and Marshall soils, respectively. Root weight, percentage water at field capacity, percentage organic matter, and soluble salts contributed most to R^2 for both soils. The factor which contributed most to R^2 in the Monona soil but not the Marshall soil was percentage sand. Factors which contributed most to R^2 in the Marshall but not Monona soil were percentage silt, cation exchange capacity, and ammonium.

Organic matter, total nitrogen, and ammonium were the only soil factors of 13 that were not significantly different between the Monona and Marshall soils. Cation exchange capacity, nitrate nitrogen, and phosphorus were the only soil factors measured that were significantly different in the Monona A and B horizon soils. The factors related to ion exchange sites may be important in explaining the differences in nematode numbers in the Monona and Marshall soils, both in the field and laboratory.

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APPENDIX

Table 3. Mean total numbers of *Xiphinema americanum* associated with President Lincoln lilac in seven levels of Monona silt loam and Marshall silty clay loam soil horizons at Hamburg and Shenandoah, Iowa, respectively, from August 1969 through September 1970

level (Inches)	Aug	Sep	Oct	Nov	Dec	Mar	Apr	May	Jun	Jul	Aug	Sep
					Monona							
0-3	375	181	23	86	63	61	0	63	218	16	46	38
3-6	343	133	33	213	55	80	13	10	111	33	123	91
6-9	93	46	13	97	38	10	15	3	41	13	50	6
9-12	70	18	13	13	8	0	16	13	30	0	8	3
12-15	40	33	18	10	10	8	5	5	11	8	8	0
15-18	23	18	20	8	0	11	0	3	3	0	16	0
18-24	21	5	6	7	3	3	0	0	5	0	6	0
					Marshall							
0-3	685	98	123	273	123	248	55	83	101	133	610	206
3-6	341	178	227	130	133	339	13	81	306	148	560	146
6-9	48	58	73	63	33	31	11	29	138	91	193	68
9-12	23	23	23	13	15	5	21	20	25	73	59	18
12-15	3	8	28	6	6	8	3	23	13	51	31	11
15-18	10	3	8	6	3	5	0	3	3	-	15	-
18-24	11	10	5	0	0	3	0	3	6	-	15	-

Table 4. Mean number of gravid *Xiphinema americanum* females associated with President Lincoln lilac in seven levels of Monona silt loam and Marshall silty clay loam soil horizons at Hamburg and Shenandoah, Iowa, respectively, from August 1969 through September 1970 and analyses of variance for each soil and the combination of soils

level (Inches)	Aug	Sep	Oct	Nov	Dec	Mar	Apr	May	Jun	Jul	Aug	Sep
						Monona						
0-3	0	0	0	0	3	0	0	0	25	0	0	0
3-6	0	0	0	0	0	0	0	0	13	0	0	0
6-9	0	3	0	0	0	0	0	0	0	0	0	0
9-12	0	0	0	0	0	0	0	0	0	0	0	0
12-15	0	0	0	0	0	0	0	0	0	0	0	0
15-18	0	0	0	0	0	0	0	0	0	0	0	0
18-24	0	0	0	0	0	0	0	0	0	0	0	0
						Marshall						
0-3	0	0	0	0	5	0	0	0	5	3	25	3
3-6	0	0	0	0	5	3	0	8	20	0	15	3
6-9	0	0	0	0	3	3	0	3	0	0	0	0
9-12	0	0	0	3	0	0	0	0	0	0	3	3
12-15	0	0	0	0	0	0	0	0	3	5	3	0
15-18	0	0	0	0	0	0	0	0	0	-	0	-
18-24	0	0	0	0	0	0	0	0	0	-	0	-

Table 4. (Continued)

Combined analysis of variance for the Monona silt loam and the Marshall silty clay loam				
Source	Sum of Squares	DF	Mean Square	F
Soils	0.759	1	0.759	15.204**
Error	0.300	6	0.050	
Depths	2.778	6	0.463	8.278**
Dates	3.323	11	0.302	5.401**
Depths X Dates	8.621	66	0.131	2.335**
Soils X Depths	0.507	6	0.084	1.509
Soils X Dates	1.925	11	0.175	3.129**
Soils X Depths X Dates	5.296	66	0.080	1.435*
Error	27.856	498	0.056	
Total	51.365	671		

*Significant at 0.05 level.

**Significant at 0.01 level.

Table 4. (Continued)

Analysis of variance for the Monona silt loam				
Source	Sum of Squares	DF	Mean Square	F
Replications	0.058	3	0.019	0.777
Depths	0.626	6	0.104	4.168**
Dates	1.639	11	0.149	5.965**
Depths X Dates	4.698	66	0.075	3.014**
Error	6.220	249	0.025	
Total	13.511	335		

Analysis of variance for the Marshall silty clay loam				
Source	Sum of Squares	DF	Mean Square	F
Replications	1.640	3	0.547	2.035
Depths	127.120	6	21.187	78.902**
Dates	15.533	11	1.412	5.259**
Depths X Dates	28.223	66	0.428	1.593**
Error	66.861	249	0.269	
Total	239.377	335		

Table 5. Mean number of non-gravid *Xiphinema americanum* females associated with President Lincoln lilac in seven levels of Monona silt loam and Marshall silty clay loam soil horizons at Hamburg and Shenandoah, Iowa, respectively, from August 1969 through September 1970 and analyses of variance for each soil and the combination of soils

level (Inches)	Aug	Sep	Oct	Nov	Dec	Mar	Apr	May	Jun	Jul	Aug	Sep
						Monona						
0-3	225	98	18	48	30	33	0	45	95	13	28	28
3-6	173	43	28	63	25	60	5	10	50	20	65	58
6-9	38	18	8	40	23	0	5	0	23	8	25	3
9-12	35	8	8	3	8	0	13	3	23	0	5	3
12-15	15	15	8	7	5	3	5	0	8	8	5	0
15-18	8	5	10	0	0	8	0	0	0	0	8	0
18-24	3	0	3	7	3	0	0	0	0	0	3	0
						Marshall						
0-3	320	43	60	98	73	93	35	38	63	65	210	123
3-6	138	60	97	67	68	133	10	48	148	93	180	70
6-9	18	20	33	28	25	18	3	18	90	63	75	40
9-12	10	15	5	3	5	0	8	5	15	35	33	10
12-15	0	5	8	3	3	0	0	13	0	18	8	3
15-18	7	0	5	3	0	0	0	3	3	-	10	-
18-24	8	5	0	0	0	0	0	3	3	-	5	-

Table 5. (Continued)

Combined Analysis of variance for the Monona silt loam and the Marshall silty clay loam				
Source	Sum of Squares	DF	Mean Square	F
Soils	6.984	1	6.984	15.423**
Error	2.717	6	0.453	
Depths	172.579	6	28.763	102.151**
Dates	31.519	11	2.865	10.176**
Depths X Dates	35.466	66	0.537	1.908**
Soils X Depths	8.978	6	1.496	5.314**
Soils X Dates	12.840	11	1.167	4.146**
Soils X Depths X Dates	25.502	66	0.386	1.372
Error	140.224	498	0.282	
Total	436.809	671		

**Significant at 0.01 level.

Table 5. (Continued)

Analysis of variance for the Monona silt loam				
Source	Sum of Squares	DF	Mean Square	F
Replications	1.077	3	0.359	1.218
Depths	54.437	6	9.073	30.784**
Dates	28.826	11	2.621	8.892**
Depths X Dates	32.745	66	0.496	1.683**
Error	73.386	249	0.295	
Total	190.472	335		

Analysis of variance for the Marshall silty clay loam				
Source	Sum of Squares	DF	Mean Square	F
Replications	1.640	3	0.547	2.035
Depths	127.120	6	21.187	78.902**
Dates	15.533	11	1.412	5.259**
Depths X Dates	28.223	66	0.428	1.593**
Error	66.861	249	0.269	
Total	239.377	335		

Table 6. Mean number of Xiphinema americanum juveniles associated with President Lincoln lilac in seven levels of Monona silt loam and Marshall silty clay loam soil horizons at Hamburg and Shenandoah, Iowa, respectively, from August 1969 through September 1970 and analyses of variance for each soil and the combination of soils

level (Inches)	Aug	Sep	Oct	Nov	Dec	Mar	Apr	May	Jun	Jul	Aug	Sep
					Monona							
0-3	150	83	5	38	30	28	0	18	98	3	18	10
3-6	170	90	5	150	30	20	8	0	48	13	58	33
6-9	55	25	5	57	15	10	10	3	18	5	25	3
9-12	35	10	5	10	0	0	3	10	7	0	3	0
12-15	25	18	10	3	5	5	0	5	3	0	3	0
15-18	15	13	10	8	0	3	0	3	3	0	8	0
18-24	18	5	3	0	0	3	0	0	5	0	3	0
					Marshall							
0-3	365	55	63	175	45	155	20	45	33	65	375	80
3-6	203	118	130	63	60	203	3	25	138	55	365	73
6-9	30	38	40	35	5	10	8	8	48	28	118	28
9-12	13	8	18	7	10	5	13	15	10	38	23	5
12-15	3	3	20	3	3	8	3	10	10	28	20	8
15-18	3	3	3	3	3	5	0	0	0	-	5	-
18-24	3	5	5	0	0	3	0	0	3	-	10	-

Table 6. (Continued)

Combined analysis of variance for the Monona silt loam and the Marshall silty clay loam				
Source	Sum of Squares	DF	Mean Square	F
Soils	12.482	1	12.482	5.903
Error	12.688	6	2.115	
Depths	152.404	6	25.401	86.511**
Dates	48.782	11	4.435	15.104**
Depths X Dates	32.921	66	0.499	1.699**
Soils X Depths	13.955	6	2.326	7.921**
Soils X Dates	16.358	11	1.487	5.065**
Soils X Depths X Dates	22.432	66	0.340	1.158
Error	146.218	498	0.293	
Total	458.241	671		

**Significant of 0.01 level.

Table 6. (Continued)

Analysis of variance for the Monona silt loam

Source	Sum of Squares	DF	Mean Square	F
Replications	4.018	3	1.339	4.539**
Depths	42.475	6	7.079	23.991**
Dates	45.472	11	4.134	14.009**
Depths X Dates	27.060	66	0.410	1.390
Error	73.473	249	0.295	
Total	192.497	335		

Analysis of variance for the Marshall silty clay loam

Source	Sum of Squares	DF	Mean Square	F
Replications	8.670	3	2.890	9.885**
Depths	123.884	6	20.647	70.625**
Dates	19.669	11	1.788	6.116**
Depths X Dates	28.293	66	0.427	1.466*
Error	72.795	249	0.292	
Total	253.311	335		

*Significant at 0.05 level.

Table 7. Analysis of variance of the regression of Xiphinema americanum numbers on oven dry root weight and 13 soil factors after removing the effect of blocks and depths for the Monona silt loam soil at Hamburg, Iowa

Source	Sum of Squares	DF	Mean Square	F
Mean	98413.6	1	98413.6	
Blocks	34414.3	3	11471.5	
Depths	149735.6	6	24955.9	
Oven dry root weight	9926.9	1	9926.9	2.65
Per cent sand	26149.6	1	26149.6	11.14
Per cent silt	1.1	1	1.1	0.00
Per cent clay	7.4	1	7.4	0.00
Cation exchange capacity	1280.2	1	1280.2	0.46
Per cent water at field capacity	6040.4	1	6040.4	2.40
Per cent organic matter	4349.3	1	4349.3	1.85
Total nitrogen	1864.9	1	1864.9	0.78
Ammonium (ppm)	258.8	1	258.8	0.10
Nitrate (ppm)	1041.0	1	1041.0	0.37
Phosphorus (ppm)	2326.8	1	2326.8	0.80
Potassium (ppm)	2206.0	1	2206.0	0.73
pH	1435.4	1	1435.4	0.43
Soluble salts	3266.3	1	3266.3	0.97
Error	13482.1	4	3370.5	
Total	356200.0	28		

Table 8. Analysis of variance of the regression of *Xiphinema americanum* numbers on oven dry root weight and 13 soil factors after removing the effect of blocks and depths for the Marshall silty clay loam soil at Shenandoah, Iowa

Source	Sum of Squares	DF	Mean Square	F
Mean	198912.9	1	198912.9	
Blocks	26399.9	3	8799.9	
Depths	292135.4	6	48689.2	
Oven dry root weight	56881.8	1	56881.8	9.31
Per cent sand	0.1	1	0.1	0.00
Per cent silt	7119.6	1	7119.6	1.10
Per cent clay	3.5	1	3.5	0.00
Cation exchange capacity	15392.9	1	15392.9	2.46
Per cent water at field capacity	9092.3	1	9092.2	1.51
Per cent organic matter	24827.5	1	24827.5	5.76
Total nitrogen	8.1	1	8.1	0.02
Ammonium (ppm)	4982.8	1	4982.8	1.06
Nitrate (ppm)	182.5	1	182.5	0.03
Phosphorus (ppm)	4346.3	1	4346.3	0.80
Potassium (ppm)	3140.8	1	3140.8	0.54
pH	1013.0	1	1013.0	0.15
Soluble salts	10588.9	1	10588.9	1.83
Error	23098.1	4	5774.5	
Total	678200.0	28		